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ELECTRIC RAILWAYS IN INDIA

(with relevant facts about electric traction in other countries and some statistics about Indian railways in general)

Including Chapters on

" Electric Street Railways,"
" Electric Traction Mathematics,"
" Single-phase Railway Projects,"
" Diesel-electric Locomotives and Railcars,"
" Electric Vehicles for Cities and Factories," (also Trolley Buses).

TWELVE CHAPTERS. NINE APPENDICES. PLATE. INDEX.
TWENTY ONE TABLES. 32 ILLUSTRATIONS. Two Graphs.

BY

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" Electric Generators, Motors and Circuits,"
" Lightning, Lightning Conductors and Arresters,"
" Hydro-Electric Installations of India."

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1940.

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Other Books by the same Author:—

1. **Indian Water Power Plants**, Rs. 5-0-0 (about 200 pages, 35 illustrations).
2. **Hydro-electric Stations in India**, Rs. 3-12-0 (1940-41). (A companion volume to "*Indian Water Power Plants.*")
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PREFACE

The publication of the present volume was adumbrated in the Author's last work entitled '*Indian Water Power Plants.*' In fact, it was at first intended to include in that work a chapter on '*Electric Railways in India.*' This was not put into effect as it was felt that the subject deserved a book to itself. As in the case of '*Hydro-electric Installations of India*' (to which INDIAN WATER POWER PLANTS serves as a supplement), the preparation of the present volume was undertaken owing to the absence of any one book containing information about the subject as a whole. There were no doubt leaflets and articles that had been occasionally published about electrified sections of one or other of the Indian Railways but there did not exist any single publication embodying the salient facts concerning all of them.

Owing to the pressure of official duties and semi-official tasks as head of the premier Engineering College of the Province of Bombay during the greater part of the year following that in which '*Indian Water Power Plants*' was printed and issued to the public, little could be done even by way of getting together the literature on the subject of Railway Electrification in India, but the idea was never abandoned. It merely lay dormant in the mind pending disposal of other matters which needed immediate attention. Moreover, it will be conceded that fresh or original artistic or mental work can not always be turned out to order. In the words of Matthew Arnold,

> " We can not kindle, when we will,
> The fire that in the heart resides:
> The spirit bloweth and is still —
> In mystery our soul abides:
> But tasks in hours of insight will'd
> Can be through hours of gloom fulfill'd."

While preparing this book, the assistance of those who were expected to be in a position to impart authoritative information was sought. One such informant wrote back to say — " I regret that the information which you require is not readily available and can not therefore be supplied." Even the Railway Publicity Bureau regretted lack of possession of 'literature and blocks on Electrical Railways in India.' The reader will realise from these statements

that the Author had to make prolonged efforts to procure the information required and to carry out his resolve to arrange the mass collected in a form suitable for study and for ready reference, and that by publishing the present volume a long-felt want of the public —to use the phrase employed in common parlance—is sought to be removed. Whilst information about electric railways and vehicles and trolley buses in India has been given as fully as possible, thanks to those mentioned on other pages under 'Acknowledgements' and to those who offered facilities during visits to the various Indian railway systems and tramway works described in this volume, some facts and figures relating to surface, sub-surface and overhead railways in other countries have also been given in this book, to show how India stands compared to them and to spur the people of this land to make further progress when peace and prosperity return, let us hope, in the not-distant future.

It is highly probable, however, that, for the duration of the War and for several years thereafter, there will be no marked advance on the stages of achievement reached by various forms of transport as recorded in this book, and the following pages should therefore continue to present a faithful picture of the situation in India in so far as it is influenced by electrification of the machinery and means of transportation; and the volume will for a long time be an accurate account of the traction stations, systems and schemes described and mentioned herein. In addition to the matter contained in the twelve chapters of the book, much useful and instructive information will be found in a condensed form in the nine appendices.

S. N.

"The Chief Commissioner ... believes that your book will be of interest to those concerned" writes Secretary, Railway Board, India. New Delhi, the 27th of February, 1940.

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3, 6, 7, 8, 9, 10, 11, 12	G. I. P. Railway, Bombay.
14, 15	Bombay Engineering Congress.
13, 16	B. B. & C. I. Railway, Bombay.
22	G. B. S. Railway, Baroda.
27	D. E. S. & T. Co., Delhi.
31	B. E. S. & T. Co., Bombay.

DEDICATED

To the just and good men
All unknown to me, then;
One group in India,
The oth'r in America:
These—made me Principal,
        Engineering College;
They—to the pinnacle
        Of scientific knowledge
Deemed me fit to be raised.
For both deeds, God be praised.

S. N.

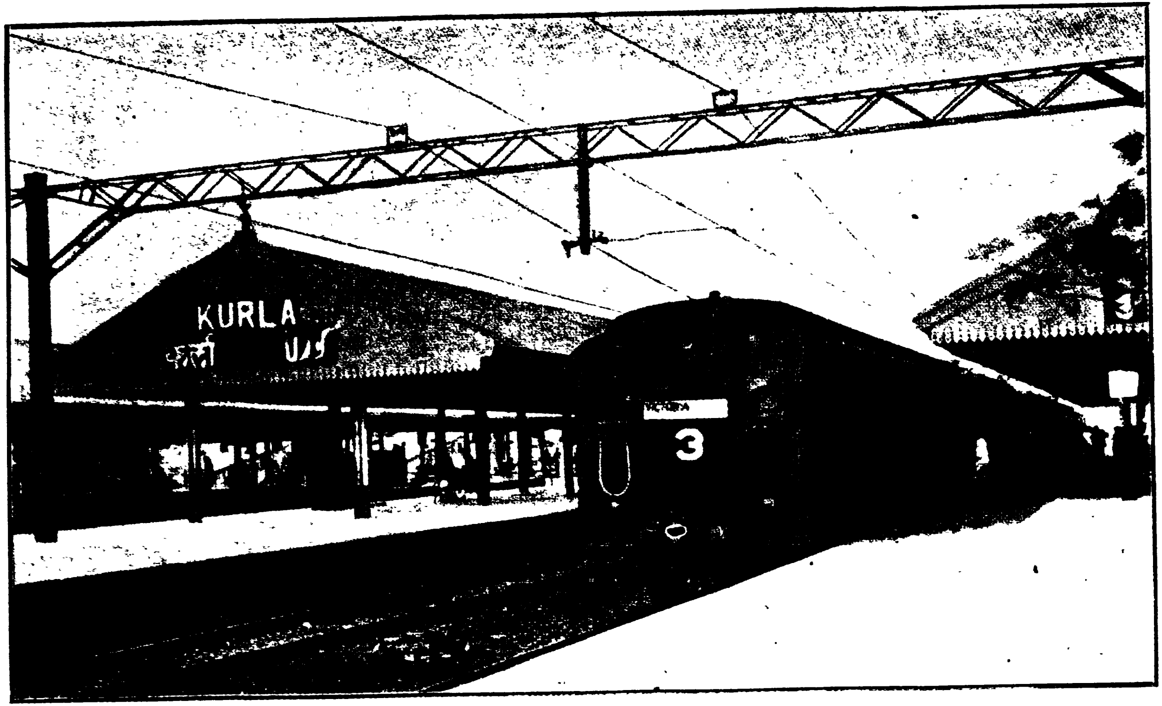

Fig. No. 1.

The First Electrified Railway Line in India.

G. I. P. Ry. Electric Train at Kurla Ry. Stn., going to Victoria Terminus, Bombay.

[Courtesy, *English Electric Co.*

Facing page 1]

CHAPTER I.

RAILWAYS IN INDIA.

HISTORICAL AND GENERAL INFORMATION.
ELECTRIC TRACTION IN INDIA.

Before taking up the consideration of Railway Electrification in India, it would be well to give some historical and general information, about railways in this country, culled from reliable sources. Within 25 years of the day of George Stephenson's '*Rocket*', the '*Fairy Queen*' of the East Indian Railway began its career in Calcutta. The East Indian and the Great Indian Peninsula Railway Companies were formed in England in 1845 i. e. nearly a hundred years ago. The first railway line to start actual working in India was that of the G. I. P. Railway; it was 21 miles long (from Bombay to Thana) and was opened on the 18th of April, 1853. The contract with the Company provided for a line from Bombay to Kalyan, the estimated cost being £500,000. The next line to be opened on 15th of August, 1854 was that of the E. I. R., 23 miles long, from Calcutta (Howrah) to Hooghly. The contract with this Railway Company was for an initial line of 100 miles from Calcutta to Rajmahal or Mirzapur, the estimated cost being £1,000,000. Then came the Madras Railway line from Rayapuram to Wallajah Road, a distance of 65 miles: this was opened on the first day of July, 1856. By the end of 1880, 6,095 miles were worked by Railway Companies in India, the cost being about 97 millions and 2,709 miles by the agency of the State, the cost being about 24 millions. The E. I. R. was taken over by the State on 31st of December, 1924 and the G. I. P. R. on 30th of June, 1925. An idea of the progress made by these Railways can be had from the figures for the *tonnage* carried by them in recent years :—

Table No. 1.

TONNAGE CARRIED BY G. I. P. & E. I. RYS.

		1934-35	1935-36
East Indian Railway	...	277,000	280,000
Great Indian Peninsula Railway	...	148,700	161,400

For further facts and figures, the interested reader may consult K. V. Iyer's '*Indian Railways*' published in 1924, P. C. Banerjee's '*Railroad Transportation*', which came out last year and the last Chapter of the present volume.

Electric Traction in India.

Turning now to the subject proper of the present volume, the following facts are worthy of mention. The first electrified line in India (see Fig. No. 1*) was a 5′ 6″—gauge section of the G. I. P. Ry. which, as stated in the preceding paragraph, was the first Railway Company to start working in India. The Electric Railway line from Bombay (Victoria Terminus) to Kurla *via* the Harbour Branch was opened on the 3rd of February 1925, extended to Bandra in 1926 and afterwards to Thana and Kalyan. The present Railway Station at Poona was opened by the then Governor of Bombay, Sir Leslie Wilson, on the 7th of July, 1925. The B. B. & C. I. Railway Company electrified the line from Colaba (Bombay) to Borivli in January 1928. Both the G. I. P. and B. B. & C. I. Railways completed the electrification of their respective local and suburban sections near Bombay by March 1929. In the same year, the G. I. P. Ry. took in hand the electrification of its main line to Poona, the opening ceremony being performed on 5th of November, 1929 by Sir Frederick Sykes, then Governor of Bombay. The South Indian Railway started the electrification of its suburban section near Madras, in 1931. About the same time, the electrification of the suburban services near Calcutta was under examination but nothing came of it and even now it is not likely to materialise, although the Calcutta Electric Supply Corporation has reduced its rates for electrical energy considerably. Not only did the G. I. P. Ry. electrify the main line to Poona in 1929, but also that to Igatpuri in 1930, the common point being Kalyan. The distance to Poona from Bombay is 119 miles and that to Igatpuri 85 miles. One is led to ask the question —' How did it come about that in Bombay the Railway Companies were able to electrify not only the suburban services but also portions of the main lines, whereas in Calcutta this could not be done in spite of the plentifulness and propinquity of coal and the consequently comparatively lower cost of generation of electric power in the erstwhile metropolis of India? ' Can it be because of the 'white fuel', with facilities for the production of power from which Nature has blessed Bombay? Certain it is that but for the development of electric power by the storage of water due to abnormal rainfall on the tops of the Western Ghats by the Tata Hydro-electric Company, it would not have been possible to proceed with the electrification of the railways in and round about Bombay, though the consideration of this work was begun in

* English Electric Co's. Railway Electrification Series, No. 51, Frontispiece.

1904, referred to in the then Governor's speech in 1911 and revived in 1913 when Mr. Merz reported on the electrification of the G. I. P. Ry. When laying the foundation stone of the Lonavla Hydro-electric Dam on February 8, 1911, Sir George Clarke, who had been an engineer before he became Governor of Bombay, opined in his speech that the B. B. & C. I. Railway suburban service ought to be electrified.

The electrification of the two Bombay railways was referred to on p. 97 of 'H. E. I. I.' in 1921 by the present Author. The costly schemes of railway electrification could not be given effect to till after the storm created by the Great European War of 1914–18 had quite blown over and the nations had resettled down to live amicably and think of peace and of projects calculated to promote prosperity and welfare of their peoples, but academic discussions continued. Mr. W. G. Barnett, Engineer of the G. I. P. Railway at Poona, read a Paper before the Bombay Engineering Congress in 1918, wherein a comparative study of steam and electric traction enlivened by mathematical calculations is given and the conclusion drawn that it is advisable to electrify in cases of heavy suburban traffic, steep gradients and insufficient capacity of track. This have been proved to be true in practice since the railways electrified the sections above referred to. Conversely, railway electrification has turned men's minds towards possibilities of further conservation of hydro-electric sources, for in the words of Mr. Sanyal in his book '*Development of Indian Railways*', published in 1930, " A new phase in train operation has been opened through railway electrification. Various sources of hydro-electric supply are now under examination and substantial economy in railway work may be secured in future years through utilisation of this source of power. In some parts of India, particularly in the South, in the Bombay Presidency and in the Punjab, electrification may be a help in meeting road-motor competition which has for some time been on the increase and has been causing great anxiety to the railways!" He gives the following strikirg figures showing the growth of the G. I. P. Ry. traffic carried by electric trains during the four years from 1925 to 1929 :—

Table No. 2.

G. I. P. RY. ELECTRIC TRAIN TRAFFIC.

Year	Track mileage electrified at end of year.	No. of Passengers (millions)	Earnings (Lakhs of Rupees)
1925–26	... 19·7	4·8	3·18
1926–27	... 71·6	16·2	13·11
1927–28	... 71·6	27·6	21·27
1928–29	... 167·2	27·0	20·72

Reference has been made above to Mr. Barnett's paper on '*Railway Electrification*', *vide* proceedings of minutes of the Bombay Engineering Congress, 1918. Other papers on this subject issued during the years 1920 and 1921 are the Technical Papers Nos. 204, 220 and 221 on 'Possibilities of Steam Railway Electrification', 'Steam *versus* Electric Locomotives for Heavy Grades' (an analysis of conditions on the N. W. Railway), and 'Further Notes on Steam *versus* Electric Traction—(i) Development of Steam Traction on the suburban services of the G. I. P. Railway and (ii) Interim Report of Electrification Standard Advisory Committee'. These papers are not available but Technical Paper No. 255 viz. 'Electric Traction' by A. R. Gundry published in 1926 is obtainable on payment from the Manager of Publications, Civil Lines, Delhi. For a list of Indian hydro-electric schemes and the correlated railways, which have been or may be electrified, the reader should please turn to Appendix V at the end of this book.

The Train And The Heavens.

As we rush, as we rush in the Train,
The trees and the houses go wheeling back,
But the starry Heavens above the plain
Come flying on our track.

James Thomson.

India's Electric Train Trio.

Pat, Bob and Rose of Canada
Came seeking peace to India,
And having 'done' old Calcutta,
They hastened thence to New Delhi,
To Simla, Lahore, Karachi.
" Enough " cried they in agony :
Coal dust and heat, noise, smell and smoke ensuing
From engines still them kept pursuing,
Instead of ease which they were suing.
Some one told them of Trains Electric
In Southern ports : then turned they right quick
To put an end to their search frantic.
In Bombay, *G*et *I*n *P*at the *G. I. P.* did cry ;
*B*ob *B*etter *C*ome *I*n cooed the *B. B. & C. I.* :
In Madras, *S*tep *I*n *R*ose said the *S. I. R.* shy.

S. N.

CHAPTER II.

ELECTRIC TRACTION IN OTHER COUNTRIES.

During the year ended June, 1938, the Southern Railway of England carried 24 million passengers in the electrified portion alone, an increase of 6½ million over 1932, the last steam year. The receipts from passenger traffic on the electrified portion amounted to £8,400,000, an increase of £200,000 on the previous year and of £1,500,000 on 1932. 'These are the clearest indication,' comments INDIAN ENGINEERING, March 1939, 'that electrification pays in spite of its high initial cost. In the case of the Southern Railway, electric train mileage exceeded steam passenger train mileage, although only no more than 38% of the total track mileage is actually electrified. Electrification is going ahead only because it has been found everywhere to result in more traffic and better returns of income, which justify initial outlay of large capital.' Railway electrification has made great strides in Sweden where water power has also been developed on a large scale. A recent publication, *Modern Transport*, states that the State Railway line between Laangsele and Boden in Upper Norrland — a distance of 310 miles — is to be converted to electrification, £440,000 having already been budgeted for this purpose, the total cost of conversion being estimated at £1,770,000. In the near future, half the total length of the State-owned railways carrying 84% of the traffic will have been electrified.

In South Africa, approximately 535 route miles or 1048 track miles have already been electrified and when the work at present authorised is completed, these figures will be increased to 590 and 1217 respectively. Practically the entire Witwatersrand area will soon be under electric working. Power for the operation of the electric trains on the Reef is supplied by the transmission network of the Victoria Falls and Transvaal Power Company — a hydro-electric undertaking — which carries alternating currents at either 40,20 or 10 kilovolts. (*South African Railways and Harbours Magazine*, July 1939, may be consulted by those interested for — a detailed account). Railway Electrification has been carried out in most countries of Europe, including Yugoslavia.

The Railway Year Book for 1938-39 gives the information that the world's railways already electrified amount to about 16,500 route miles or over 26,000 track miles. For the working of these lines,

approximately 2,000 electric locomotives and 12,000 motor coaches, and trailers are used. Great Britain has at present about 702 route miles or 1746 track miles of electrified railways, excluding lines such as the London Tube Railways and the Liverpool Overhead Railways which have always been electrically operated. In France, Holland, Japan, Belgium, Australia, New Zealand, India and many other parts of the British Empire, 1500 V d. c. has been adopted as standard for line electrification: 3000 volts d. c. is used in Spain, Mexico, South Africa, Belgium, Poland and the Central and Southern divisions of the Italian Railways belonging to the State. Single-phase a. c. is standard for railway electrification in Norway, Sweden, Lapland, Germany including Austria, Hungary and Switzerland — the frequency of the supply being 15 to 16–2/3 cycles or periods per second. In America including Canada, wherever the single-phase system is used, the frequency is 25 cycles per second, and the voltage 11 to 15 kV : where the d. c. system is used, 600, 1200, 2400 or 3,000 volts is employed as the line pressure. Apart from a short line in Spain, three-phase a. c. is used only in Italy (which leads other countries of Europe in electric traction, see Table 13 in the last chapter) with a nominal contact line voltage of 3300 volts but part of the Italian system is being converted to 3000 volts d. c., *vide Overseas Engineer* for June 1939; one line being however worked at 4000 V d. c. Single phase 12,000-volt 25-cycle supply is used for operating the trains of the Pennsylvania Railroad, which embraces the largest system in the world, controlling the lines working between the Mississipi River, the Great Lakes and the Atlantic seacoast of the United States of America. Electrification of a portion of this Railway was begun in 1905 and other portions were electrified in 1906, 1910, 1915, 1918, 1924, 1928, 1930, and 1936. The entire electrification embraces 1405 miles of track or 364 miles of route. For the New York-Washington main-line service, 686 trains run daily, being made up of the following:—(*G.E. Review*, February 1936).

Table No. 3.

PENNSYLVANIA ELECTRIC TRAINS.

Type of train	No. of trains	Train-miles	Locomotive-miles.
Multiple-unit Passenger ...	448	9,648	...
Locomotive „ ...	191	20,127	21,118
Through freight (goods) ...	47	4,965	10,922
TOTAL ...	686	34,740	32,040

The United States, the cradle of electric railways, had 44,676 miles of track of all sorts (including that inside cities on streets, etc.) operated by electricity in 1917, the Boston-New York line alone being 185 miles long; another inter-urban line, then in actual operation, being that from Jersey City to Philadelphia.

The London and North Eastern Railway Co.'s 'all-in' electrification scheme is unique in as much as all trains, whether passenger, goods or coal, running between Manchester and Sheffield are pulled electrically. Electric locomotives have facilitated the handling of heavy goods trains on long grades in the Pennines. The mileage electrified last year amounted to 74·56 route miles or 292.71 track miles. Eighty-eight electric locomotives replaced 181 steam locos. They cover 1,304 million miles per year. Moreover, the capacity of the Woodhead tunnels has been increased by 25% as a consequence of electrification, owing to elimination of smoke, improvement of acceleration and other factors contributing to rapid and comfortable movement. About 75% of the Federal Railway system of Switzerland has been electrified. Large-scale railway electrification has also been carried out in Scandinavia where water power is plentiful and has been harnessed in many places. The same is true of the United States of America and the U. S. S. R. (Russia), particularly in regions where heavy gradients are met with.

Electric Locomotives of large sizes are in use in the most important countries of the West; among the largest being 12,000 H. P. in Switzerland (of 2-articulated sections; classed as Ae 8/14, 8 out of 14 axles being motor-driven), 5,800 kW in Germany, and 5,000 H. P. in U.S.A. (the last being a steam-electric loco. which consists of two turbo-generator sets, each 2500 H. P. using steam at 920° F. and 1500 lbs. per square inch). The 5000 H. P. electric-contact locomotive of the Pennsylvania Railroad can haul a 1200-ton train for a distance of over 200 miles in about as many minutes. For the details of the relay protection of power supply system for the electrification of this Railroad (New York-Washington -Harrisburg), the interested reader is referred to the June 1939 number of '*Electrical Engineering*', published by the American Institute of Electrical Engineers. The August 1939 issue of the same Journal contains an instructive article on 'Signalling on Electric Railroads.' Other allied interesting subjects will be found dealt with among the Appendices at the end of the present book.

An 'automatic goods' 2′6″-gauge electric railway which has been in successful operation since 1929 is that of the G. P. O., London, between Paddington Station and the Eastern District Office in

Whitechapel. It is unique because it comprises a complete traction system — rolling stock, substation plant, 14½ miles of third-rail system with feeders and automatic signalling, indicating and control equipments for 8 stations —, on which a busy flow of traffic is maintained by driverless trains, *vide* English Electric Co.'s booklet on Transport, which contains the following comment worth consideration in connection with diesel-electric traction (the subject of Chapter VII of this book)—

"When a large power station with its inherent overload capacity is behind the system, excess weight in electrically-propelled vehicle does not make so marked a difference in performance. It is obvious, however, with internal-combustion engined coaching stock, that the lighter the vehicle the better its performance in acceleration, maximum speed and fuel consumption. In the case of locos., as weight is usually required for adhesion, reduction in weight is not of such great importance."

Driverless trains, usually associated with models of railways and run by current from electric accumulators, are useful from an instructional point of view as the various operations of starting, stopping, reversing the direction, switching at points, shunting, signalling etc., can be demonstrated inside a single hall. One such model railway made by Mr. H. J. Mulleneux, Chief Electrical Engineer, G. I. P. Ry., could be seen in Bombay and another (installed in the electrical laboratory of the College of Engineering some years ago when the Author was Professor of Physics and Electrical Engineering there) can be seen in Poona by arrangement with Prof. B. B. Sarkar. The particulars of this railway are as follows :-- 1¼ in. gauge ; 10 volts, permanent magnet motors ; 3rd rail between the running rails. ' A Plea for School Railways' is the title of an article in the August 1939 number of South African Railways and Harbours Magazine. Such a plea is still more appropriate for India which is reputed for the richness of its natural resources but is dubbed backward on account of the apathy of the people towards industrial development of the modern mechanised variety. Our young men must learn to use their own hands and bend their own minds to the tasks of making and working machines and appliances of all sorts that are calculated to contribute to the promotion of peace and prosperity, e. g. railways, automobiles, aeroplanes, ships, tractors, dynamos, etc.

CHAPTER III.

ELECTRIFICATION OF THE G. I. P. RAILWAY HARBOUR AND SUBURBAN SERVICES.

—: o :—

History.

The first railway to be electrified in India was the 5 6″- gauge section of the G. I. P. Railway known as the Harbour Branch, from Bombay to Kurla, which was opened by His Excellency Sir Leslie Wilson, the then Governor of Bombay, on the 3rd of February, 1925. This electrification was undertaken in order to meet the traffic needs of the Gateway of India, which were intensified as a result of the city development schemes launched at that time by the Government of Bombay, the City Improvement Trust and the Bombay Port Trust. The Secretary of State sanctioned the electrification of the Bombay-Thana section in August 1922 and that of the Thana-Kalyan section in June 1923, but electrification was carried out in the first instance for a distance of 9½ miles only up to Kurla, as this station is a more suitable terminus than other stations for the Harbour Branch, the urgency for which was felt by the Trustees of the Port of Bombay. Fig. No. 2 is a map of the area covered by the G. I. P., and B. B. & C. I., suburban electrified railway lines.

Exactly a year after the opening ceremony referred to above, a connection was made on February 3, 1926 from the Ravli junction of the Harbour Branch to the Mahim station of the B. B. & C. I. Railway, thus giving direct access from Bandra (B. B. & C. I. Railway) to the new Cotton Green as well as to Victoria Terminus (G. I. P. Railway). The suburban lines from Kurla to Thana were electrified *via* the Harbour Branch on June 21, 1926 and the Main suburban lines (from Bombay to Kurla) on November 1, 1926; the route mileage being thereby increased to 20¾ miles and the track mileage (including sidings) to about 77 miles. Soon after (in March 1929) came the extension to Kalyan, which is 33¾ miles away from Victoria Terminus*, the track mileage (including sidings) being thereby increased to about 107 miles. The intervening areas having become thickly populated and the traffic having increased rather rapidly, the line from V. T. (Bombay) to Kalyan had been quadrupled in 1917 i.e. before electrification was begun. The average speed is, now, 26½ m. p. h.; the halt at each station being ½ minute.

* The stops are about 1 mile apart between V. T. and Kurla, about 2 miles apart between Kurla and Thana and about 2·5 miles apart between Thana and Kalyan.

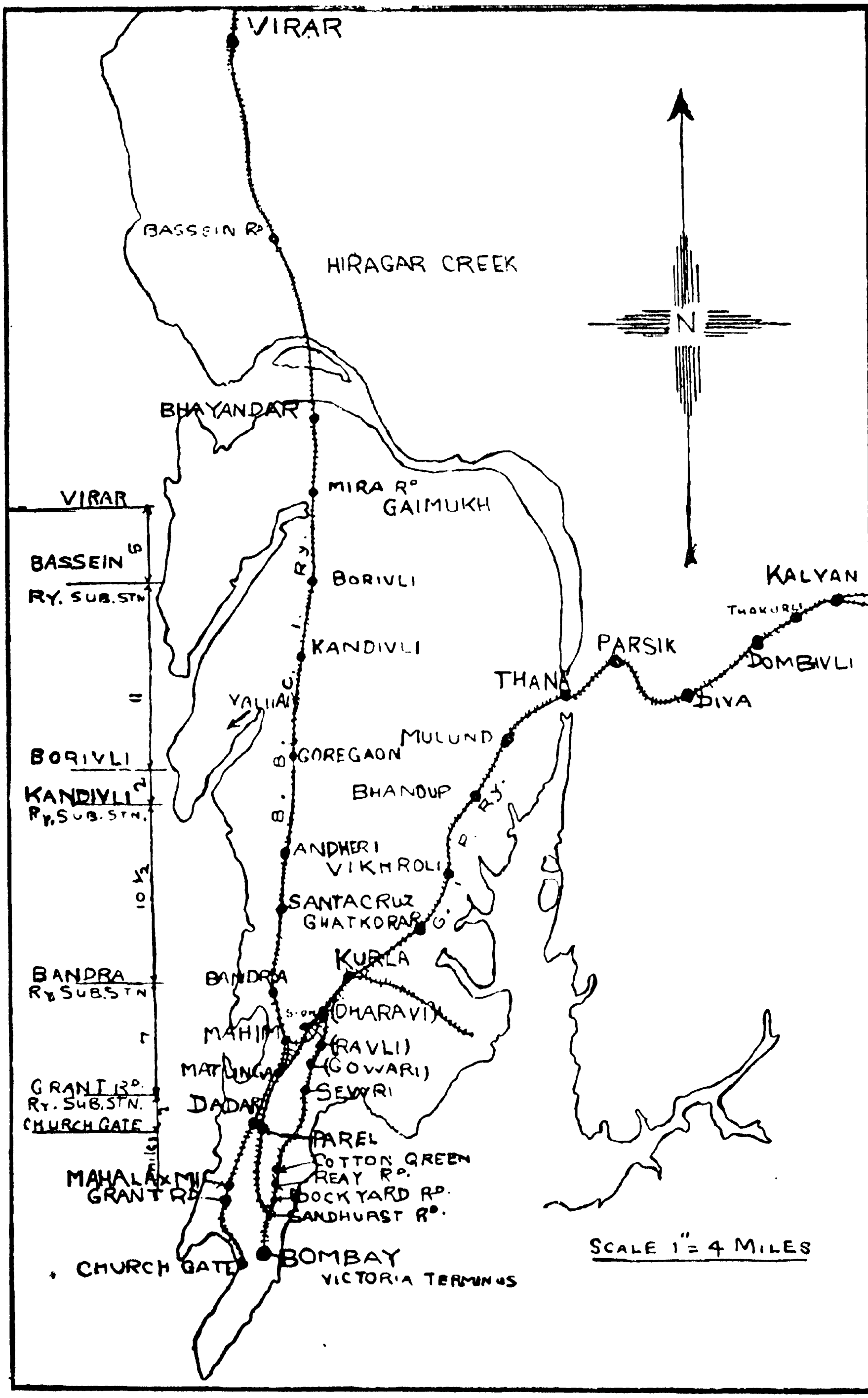

Fig. No. 2.
G. I. P., and B. B. & C. I. Ry. Suburban Electrified Lines.

Description of the Harbour Branch.

After leaving Kurla, the line runs along the Sion causeway passing round the Sion Hill on the Harbour side and skirting the villages of Kolvada and Agarwada, thence keeping to the east of Gowari, it runs to Sewri village and Tank Bunder (now called Reay Road Station). After leaving this station, the line rises on an incline of 1 in 42 to cross Reay Road by a skew girder bridge, being carried thence-forward on a series of masonry viaducts and supporting grounds on Bhandarwada Hill till it reaches Wadi Bunder Goods Yard which it crosses on a heavy steel viaduct, forming the Sandhurst Road High Level Station. After thus going over the Main Line, the Branch drops to the level of the former and runs parallel to it till Victoria Terminus is reached.

Necessity for Electrification.

(1) The gradients on the Wadi Bunder and Sandhurst Road viaducts ruled out steam operation of the trains. (2) The initial capital cost of a steam service for the Harbour Branch and Mahim Chord was estimated to be Rs. 81.68 lakhs against Rs. 72.80 lakhs for an electric service — the disparity in cost increasing with increase of traffic. The retention of a steam service would have cost Rs. 6 crores (if not more than that), whereas by a gross expenditure of Rs. 108 lakhs on electric substations, overhead equipment, etc. *plus* Rs. 151⅓ lakhs on rolling stock, the Railway could deal confidently with all traffic. (3) The operation cost per train mile with steam operation was estimated at 30·62 annas against 25·41 annas for electric operation for the Harbour Branch and 39·79 as. against 29·00 as. for the line up to Kalyan.

Advantages of Electric Traction.

1. The improvement of the passenger train service both as regards schedule speed and frequency of trains.
2. A considerable increase in the carrying capacity of the line without costly additions to the permanent way.
3. An increase in the capacity of terminal stations.
4. A reduction in operating costs.
5. Improved punctuality.
6. Development of residential areas.
7. Cleanliness in operation.

A traffic density of 20,000 train-miles for a passenger service, or of 3 million ton-miles, per mile per annum usually justifies electri-

fication. Another advantage of electrification of a suburban section is that it permits of the use of multiple-unit trains. This system originated in the United States of America and was known as the Sprague system there. Two, three or four coaches may be coupled together to form one unit, one of them being equipped with the necessary electrical equipment including motors : and one or more units can also be coupled.

Advantages of Multiple Unit System.

(a) The train unit can be operated with equal facility from either end.

(b) Whether the train is made up of one or more train units, the motive power is always proportional to the weight of the train.

(c) The time required to reverse the direction of the train at a busy terminal is determined by the time required to exchange the passengers, the detachment and re-attachment of the locomotives being entirely avoided.

Electric Supply for Suburban Service.

The current for operating the train motors etc., is obtained from the Tata Trio of Hydro-electric Power Companies which transmit power (3-phase 50-cycle 100-kV) from three widely-separated generating stations situated at the foot of the Western Ghats (for details, please see the present Author's books, *Hydro-electric Stations in India* and *Indian Water Power Plants*). After arrival in Bombay, the line pressure is reduced at the Dharavi Receiving Station to 22 kilovolts, at which voltage power is supplied to the Railway sub-stations at 4 places. Those at Kurla and Wadi Bunder are fed by means of underground cables from Dharavi, and the Kalyan and Thana sub-stations are fed by overhead lines from Kalyan, Receiving Station, see Fig. No. 15. The sub-stations are located alongside the track at intervals averaging about 8–10 miles in the suburban areas and 12–14 miles on the main line beyond Kalyan.

Suburban Sub-stations, Etc.

At the sub-stations, transformers reduce the pressure from 22,000 to 550 volts for rotary converters. Each set consists of two machines, each rated at six-phase 550–volts on the a. c. side and 750 volts on the d. c. side, and having a continuous rating of 1,250 kW and a 2–hour rating of 1,500 kW and running at 600 r. p. m., being started by a pony motor, cooled by a fan on the armature, protected by a circuit breaker against overloads and provided with necessary accessories. The positive lead of each set is connected to the 1,500–V

bus bar through a breaker and the negative to the other bus bar through a resistor (the latter being short-circuited during operation). At the Wadi Bunder, Kurla and Thana sub-stations, the circuit breakers are of the switch-board type; but at Kalyan they are of the truck type, a cross connection being provided to maintain continuity of feeder, in case a truck is withdrawn for maintenance. The Wadi Bunder and Kurla sub-stations have 4 sets of rotaries each, while those at Thana and Kalyan have 3 sets each. All the suburban sub-stations are manually operated. There are five track section cabins provided with circuit breakers which are worked by motors by alternating current supplied by nearby sub-stations or signal cabins.

Overhead Equipment.

The D. C. feeders from the sub-station are carried underground, the negative (1.0 sq. in.) to the rails and the positive (0.75 sq. in.) to the overhead conductor. The rails are bonded at joints by thick stranded copper bonds to ensure continuity and they are also cross-bonded to each other and from track to track at various places to reduce stray current and avoid electrolysis and consequent damage of water mains, etc. The overhead conductor is of copper, 0.625 sq. in. in sectional area per track, made up of a contact wire — a 0.25 sq. in. solid grooved copper wire with a breaking stress of 20 tons per sq. in. — suspended by droppers from the stranded-copper catenary wire of 0.375 sq. in. area, the latter being suspended through 2 ·cap and pin-type insulators on the Thana-Kalyan section and the main line from the lattice-steelwork structures which are erected normally 250 feet apart, but being carried on 2 bracket insulators on Bombay-Thana section except for special head-spans. Cantilever structures are used for single track work and a special head-span construction is used in yards in order not to upset the yard layout and impede the normal working of the yard. The track is divided into sections by means of track-sectioning cabling and overhead-equipment section switches. Any one of the sections can be isolated from the rest for repairs or inspection witout disturbing the supply to other sections. The third-rail system has not been adopted although it would have been cheaper than the overhead system. The voltage-1500 volts-is too high to be used near the ground level because of the danger of floods and risk to pedestrians who may trespass on the railway track and because of the difficulty of insulating and guarding the rail satisfactorily. The height of the contact wire is normally 16′6″ above the level of the rails but it increases to 18′ at level crossings and drops to 14′10″ at certain overbridges.

Current Collecting Contrivances—Driver's Compartment.

From the contact wire, the current is conveyed to the motors under the trains by means of pantographs which are well insulated from the roof of the motor coach. There are two pantographs on each coach but only one of these can be in use at a time. Current collected by bow-shaped sliding 'skates' is taken to the main fuse on the roof and thence to the 1500-volt room — usually called the high-tension chamber — by means of cables.

The pantograph can be raised by a hook-stick but is usually lifted by a vacuum hand pump. The pressure against the contact wire does not however depend upon that of the air, being due to four tension springs which work by means of chains and cams giving a turning movement to the main pantograph shafts and ensuring a uniform pressure being applied throughout the working range which is about 6 feet. The exhausters are kept running always and are employed to work the brakes, whistle and pantographs.

The driver's compartment is just in front of the high-tension chamber which is a sheet-steel structure wherein all the equipment is mounted upon a portable steel frame, so that it may be withdrawn when required for repairs or inspection. Access to the chamber through a hinged steel door can be had from the driver's compartment but a special air-valve is fitted to prevent a pantograph being raised whilst the door is open; otherwise, the equipment would be rendered alive at 1500 volts.

Rolling Stock.

The rolling stock for the electric trains employed for the suburban traffic consists of a number of 4-coach units -- one motor coach the second from one end) and 3 trailers -- made up into 4-coach and 8-coach trains. There are also 3-coach and 6-coach trains. Each motor coach is equipped with four D. C. series motors, 750-V 275-H. P. (one hour rating) each; one pair of motors being axle-suspended in each motor coach bogie and driving 43″-diameter wheels through reduction gears of a ratio of 75 to 21, the maximum speed on the level being 50 miles per hour. The original steel stock coaches are probably the widest coaches in the world being 12′ wide overall-- the unusual width being employed in order to allow for the heavy 'rush' traffic incidental to suburban service in a large city. The traction motors originally supplied had special air valves to ensure their working well even when the track is under 2 feet of water. There are 53 motor coaches and 153 trailers, the majority of which

are 10 feet wide. A third class coach will seat 110 to 120 passengers.* The following particulars regarding the dimensions of a 12′-wide coach will serve to give the reader an idea of it:—Length 68′, width 12′, centres of bogies 48′, bogie wheel base 10′, gauge 5′6″, height of roof above rail 13′9″, trailer tare 48 tons, tare of motor coach 77 tons 2 cwts. Owing to the great width, these carriages overhang the platforms by about 6 inches. There are 13 trains of 4 such coaches in use on the Harbour Branch. On the main suburban section, there run 38 trains of 4 coaches, each 10 ft. wide with height of roof above rail 12 ft. 7¼ in., trailer tare 42.56 tons, tare of motor coach 71.9 tons — other particulars being the same as for a 12′-wide coach. The 10′ stock is fitted with hook and link couplings and the 12′ stock with automatic M. C. B. couplers; both using A. V. brakes of the same standard as employed on all Indian Railways.

Any number of motor coaches (up to 3) and trailers (up to 9) can be assembled in any manner or sequence and driven from either end of a train, being controlled through a 19-core cable running the whole length of the train.

Driving and High-Tension Equipments.

Between the roof-fuse and the apparatus in the high-tension chamber, a main circuit-breaker and a pair of line-breakers are interposed. Starting resistances usually called rheostats are connected to the line and to the motor armature and field winding by means of contactors which are worked by a cam-shaft operated by a small motor. Fig. No. 3 shows the high-tension chamber, also driving control, of a G. I. P. Ry. motor coach.

The connections can be altered as desired to get 12 different operating conditions for starting and driving the motors. When a train is to be started, the master controller in the driving compartment is turned to the 'on' position after the emergency release button in the control handle has been pressed down. The control wires then close the line circuit-breakers whereby a pair of control contacts are closed, putting the four motors in series with one another and with the starting resistances. The current in the acceleration relay becomes reduced owing to back e. m. f. after the motors begin to run; this allows the controller to move one step forward. The starting rheostat is thus automatically cut out in 6 steps. Thus the motors receive a pressure of 375V each. They are then connected in pairs through starting resistances which are cut out in 5 steps. The change to parallel connection having been made, each motor gets its full pressure of 750 volts, and 2 paralleled groups are formed of 2 motors in series. If very high speed is required, the controller is turned to the tapped-field position; some of the coils of the series fields are thereby short-circuited, the field strength is reduced and the speed raised. The master controller is

* A single car of this capacity would require a 250 H. P. motor. Four such coaches require a total of 1000 H. P. or four 250-275 H. P. motors.

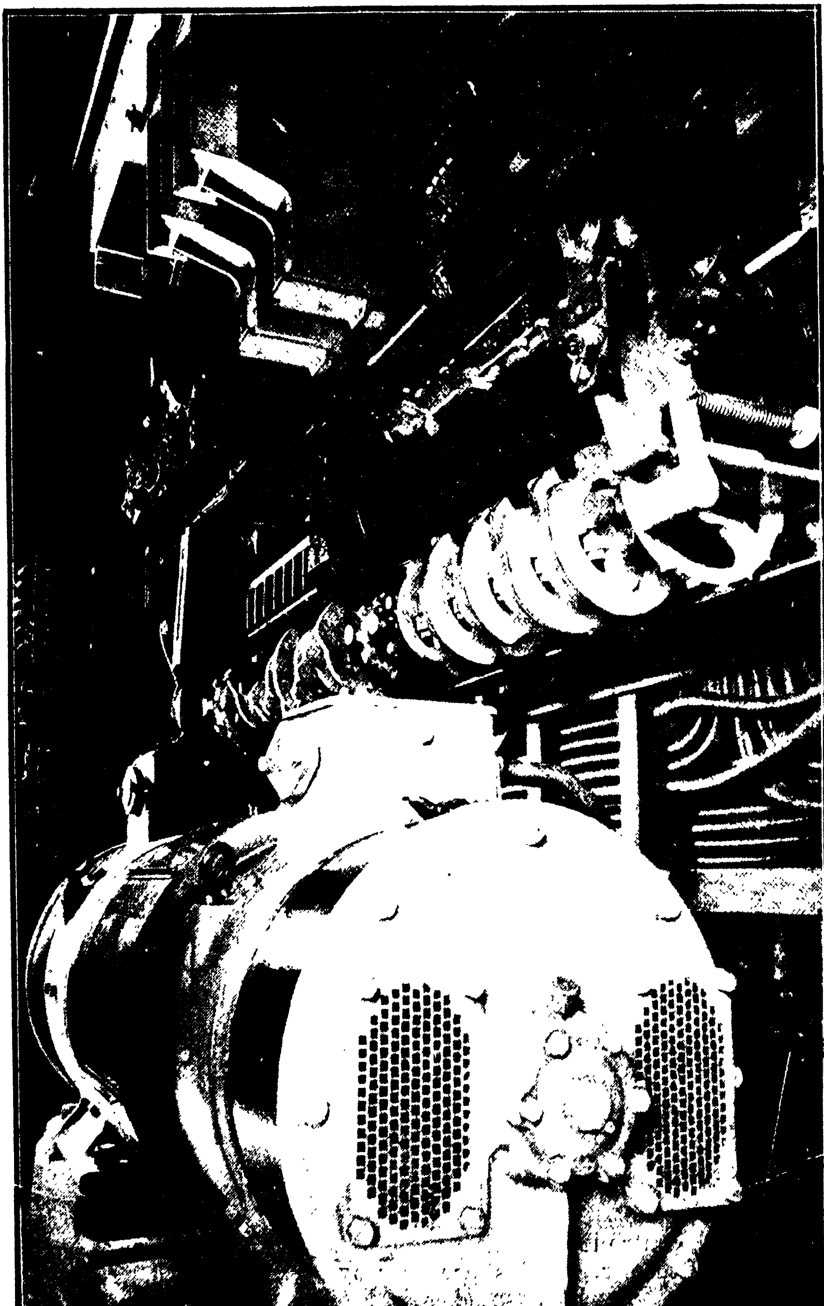

Fig. No. 3. G. I. P. Ry. Motor Coach High Tension Chamber, also Driving Control.
(Courtesy of G. I. P. Ry.)

released in case of an emergency: normally it is turned to 'off' position and the brakes applied if the train is to be stopped. The line breakers are so inter-locked that they can not be put 'on' again unless the starting gear is in the 'off' position. In addition to the master controller, the driving compartment contains devices for raising and lowering the pantographs, starting and stopping the vacuum exhauster for working the brakes, turning the emergency lights 'on' or 'off', working the whistle, operating the signal in the guard's van, resetting the overload relay, etc. Should any accident incapacitate the driver causing removal of his pressure on the emergency button of the handle, (which with this button is appropriately called the dead-man's handle) the line breakers open automatically and the brakes are put on simultaneously, thus bringing the train to a standstill. For driving a train in the backward direction, the reverser is worked by a handle on the master controller whereby the field connections of the driving motors are reversed. This handle is so interlocked that it can not be worked unless the controller is in the 'off' position and the train is therefore stationary. The master controller which is of the drum and segments type is used for operating the control-gear in the high-tension chamber. Fig. No. 4 shows a cam-shaft controller and control equipment for a G. I. P. Railway traction motor coach. (Eng. El. Co.'s. Booklet.)

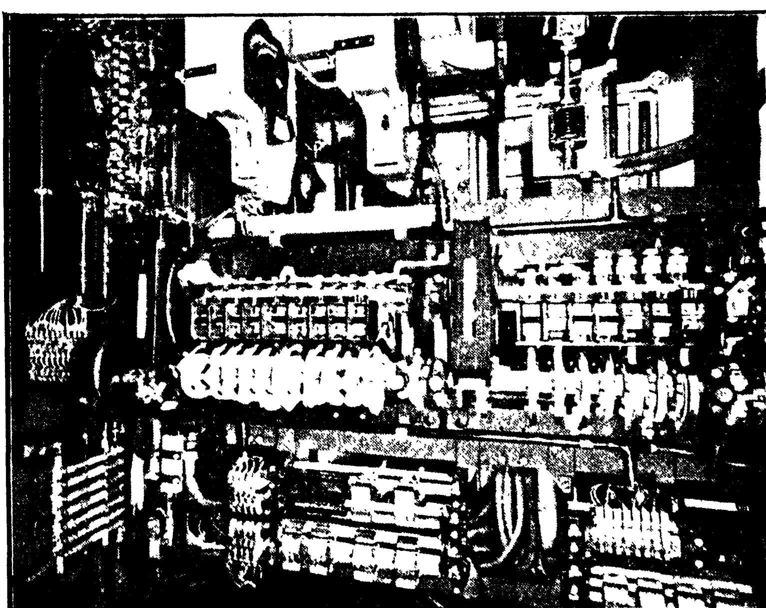

Fig. No. 4. Control Equipment, including Camshaft Controller.

(Courtesy of English Electric Co.)

Auxiliary Apparatus.

MACHINES.

1. Motor-generator Set to change from 1500V to 110V for lights and control devices.
2. Rotary Exhauster, for the pantographs and vacuum brakes, driven by a 1500V motor.

EQUIPMENT.

3. Field reverser, for driving in the backward direction.
4. Cam group for resistances and field tap contactors, for increasing the speed.
5. Relay for automatic acceleration,
6. Circuit breaker with overload coil and electrical resetting arrangement.

Only 110-volt or low-tension wires are brought for lighting and control purposes to the driver's compartment through a multicore cable carrying at its ends plug and socket couplers. These wires ensure that the driver can with perfect security energise the various devices and carry out the desired operations.

N. B.—This chapter and the next chapter have been kindly corrected by the General Manager and Chief Transportation Officer, G. I. P. Ry. For the llustrations, the Author is indebted to the Publicity Officer of this railway and to the Officer in charge of the Bombay Office of the English Electric Company.

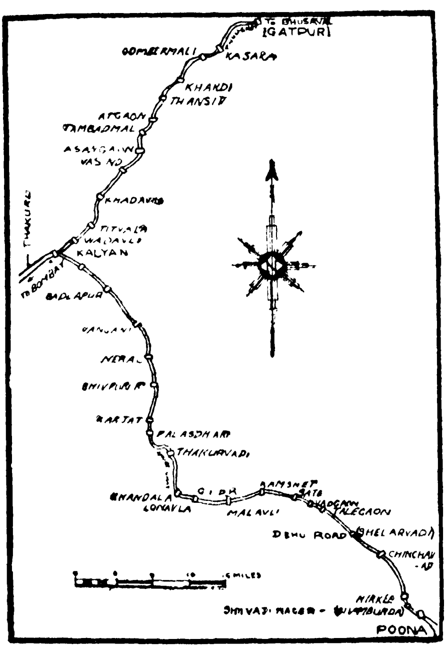

Fig. No. 5. G. I. P. Ry. Electrified Main Lines.

CHAPTER IV.

ELECTRIFICATION OF THE G. I. P. Ry. MAIN LINE.*

Electric traction becomes a sound financial proposition in the case of heavy suburban service because of the larger acceleration and schedule speed rendered possible with the electric motor in comparison with the steam engine, and also in the case of mountainous areas where steep gradients present difficulties not easy to tackle with steam locomotives. Electric locomotives can not only haul heavy trains and wagons up grade more economically and rapidly but when going down a grade can return electrical energy to the supply system by reason of the properties inherent in electric motors enabling them to work as generators under such circumstances. Thus, savings are effected in the costs for power and for the maintenance of brake shoes and wheel tyres. The multiple-unit system which is suitable for suburban service can not always be used for the main line, as it is not well adapted for high speeds or goods traffic (though it is used in South Africa for the latter), and it does not allow of vehicles being hauled from non-electrified or non-wired sections of the line. Electric locomotives are therefore generally used for main-line traction.

The portions of the G. I. P. Ry. main line which have been electrified up to the present date are :—Bombay (Victoria Terminus) to Kalyan (33 miles). Kalyan to Igatpuri, to the North-east (52 miles) and Kalyan to Poona, to the South-east (86 miles). The total track distance which has been electrified comes to 408 miles.† The feature which is of paramount interest in this electrification scheme is the presence of ruling gradients of 1 in 37 on the Thull Ghat between Kalyan and Igatpuri for a distance of 10 miles and on the Bhore Ghat between Kalyan and Poona for a distance of 18 miles. This justified the expenditure of Rs. 6,42,70,000 gross on the main line electrification. Fig. No. 5 shows the G. I. P. Ry. main lines which have been electrified up to the present time.

History.

The first cart road up the Bhore Ghat was constructed in 1830. The mail service cart took 24 hours and cost a passenger Rs. 100.

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* Figs. 6 to 12 are reproduced, with thanks, from the G. I. P. Ry. Booklet issued at the inauguration of the Main Line Electric services on 5th of November, 1929.

† The single-track suburban track mileage, including sidings, is 571 miles ; the total route mileage being 181.4 miles. *Lydall.*

About the year 1863, the first through railway train ran to Poona from Bombay in 6 hours. Electric trains started running in November 1929, taking about 3 hours for the same distance — the '*Deccan Queen*' doing the run in only 2¾ hours. The electrification of the section from Kalyan to Igatpuri was completed in July 1930. The railway fares in force now are:—Rs. 2/6 for 3rd. class, Rs. 7/7 for 2nd. class, and Rs. 14/14 for first class, passengers.

Generating Station.

Electric power for the suburban service is obtained from the Tata Water Power Companies' system, but for main-line operation it is furnished by the Railway Company's own steam station at Thakurli near Kalyan. This station — formerly called the Chola Power Station and now the Kalyan Power House — cost about a crore of rupees and has an aggregate capacity of 40,000 kW or 53,500 H. P. approximately. From Feb. 1940, the G. I. P. Ry. steam station will be connected to the Tata hydro-electric system for the benefit of all concerned, as efficiency and economy will be secured. Each of the four G. I. P. Ry. Kalyan turbo-generators can produce a. c. power amounting to 10,000 kW at 6,600 volts, 50 cycles per second. The pressure is raised to 100,000 volts by transformers installed out of doors, see Fig. No. 8. The large quantity of cooling water required for the turbine condensers is taken from the Uhlas River: on the left bank of which the protected pumping station, in which five motor driven pumps (motor b. h. p. 1269: pump capacity, 64,000 gallons per minute) are installed, is situated about 1000 feet from the Power Station. The used-up water is discharged 2000 feet down stream.

Boiler House.

The boiler house contains the coal and ash handling plants, *six* water-tube boilers with their feed-water and heating systems, etc. The boilers can be fired by either coal or oil or by both. By working all the six boilers simultaneously, 630,000 lbs. of steam could be produced per hour. Each boiler is, however, meant for a normal output of 60,000 lbs. and a maximum output of 75,000 lbs. of steam at a pressure of 260 lbs. per square inch and a temperature of 700 degrees Fahrenheit. Normally coal is used as the fuel but to meet sudden fluctuations of load, oil-firing can be resorted to. When fired with both coal and oil, each boiler can give 105,000 lbs. of steam per hour. The fuel normally used is cheap slack coal from the Central Provinces, broken into very small chips, conveyed from a dumping pit to hoppers by an endless belt (total capacity 1000

tons), and fed on to a mechanical chain-grate stoker from an overhead bunker through chutes. The stoker is driven by an electric motor through gearing and can thus be run at any speed desired. Each boiler has its separate Green's economiser, superheater, induced-draft fan, soot blower, etc. Steam from the boilers goes to the Receiver from which any of the turbines may be fed. Ash is disposed of on an endless belt which discharges into hopper wagons.

Turbine Room.

The turbine room, shown in Fig. No. 6, contains *four* turbo-

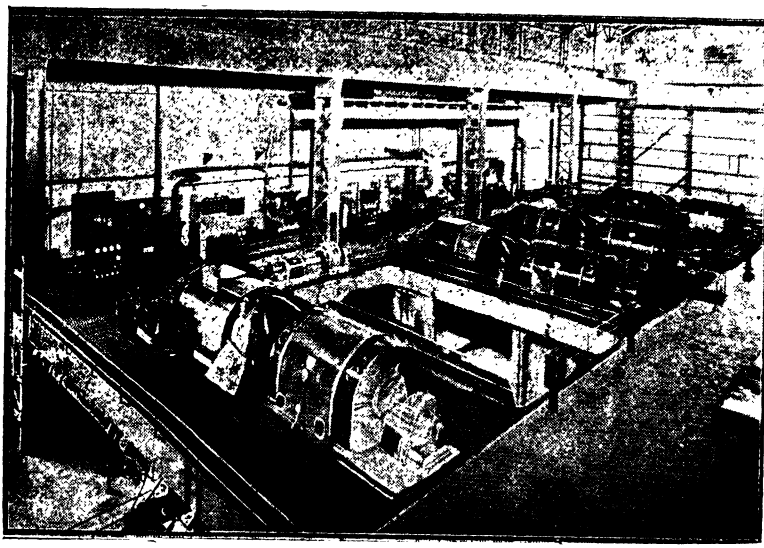

Fig. No. 6. G. I. P. Ry. Kalyan Power House—Turbine Room.
(Courtesy of G. I. P. Ry.)

alternator sets, each of 10,000 kW capacity and 2 non-condensing house-service sets of 350 kW each. Each of the main sets consists of a turbine, to which a three-phase 11,000–kVA and 6,600–V alternator is direct-coupled, running at a normal speed of 3,000 r. p. m. The turbines are of the pure reaction type, and are designed to work over a vacuum of 28″. The expansion of steam is effected in 42 stages, each comprising 2 rows of stainless-steel blades. The height of the first blade is 1–5/16″ on a diameter of 19″ and the last blade is 13–3/8″ high on a diameter of 40″. The set can generate 16,500 kW for 2 minutes. This is secured by passing the first 20 rows of blades. The governing of the turbine is by an oil-relay valve. An eccentric bolt type shaft governor is also provided to shut an emergency run-away valve when the speed exceeds 3,300 r. p. m. The bearings are lubricated by oil forced through them from a reservoir by a rotary oil-pump geared to the turbine governor shaft. About 10% of the lubricating oil is automatically filtered every day. The average consumption of each turbine is 10·486 lbs. of steam per kilowatt-hour.

The condenser for the main turbine is of the double-flow type with a cooling surface of 14,500 sq. ft. As the circulating water is saltish,

zinc blocks are placed in the water boxes to avoid corrosion. Each condenser is designed to deal with 105,300 lbs. of steam per hour normally and 195,000 lbs. for overload of 2 minutes duration; the circulating water used being 14,400 and 19,000 gallons per minute respectively. All pipe connections to the turbines are provided with elaborate expansion pieces. The condenser rests on four pedestal springs and is not rigidly fixed to the foundation. For each generator, there is a 11,000 kVA transformer to step up voltage to 110,000V and a 1800 kVA transformer to lower it to 415 V.

The house-service set, which is used to start the various auxiliaries after a complete shut-down of the main generating sets, consists of a 4-stage Curtis non-condensing turbine rated at 9,000 r. p. m. geared to a 350-kW 415-V 1500-r. p. m. 3-phase alternator which can be started at any time without having to be dried out first, even though it has remained unused for a long time. The average steam consumption is 27.5 lbs. per kWh. Other auxiliaries in the turbine room include:—ventilating fan and air cooler (for 40,000 cu. ft. of air per minute,) vertical extraction pumps, steam jet vacuum augmenter, steam ejector, air pumps, oil coolers and filters, etc. In addition to the transformers mentioned above, there are four 25 kVA 415/110 V single phase transformers. Besides these devices for giving a. c. at a lower voltage, 110 volts d. c. for charging the battery etc., is obtained from two 25 kW 415/110 V motor-generator sets. A 500-Ah 110-V battery provides the current required for switch operations and for emergency lighting.

Besides rooms for the boilers and turbo-alternators, the Power Station comprises the following:—control room apparatus shown in Fig. No. 7, high-tension Reyrolles switchgear, English Electric e. h. v.

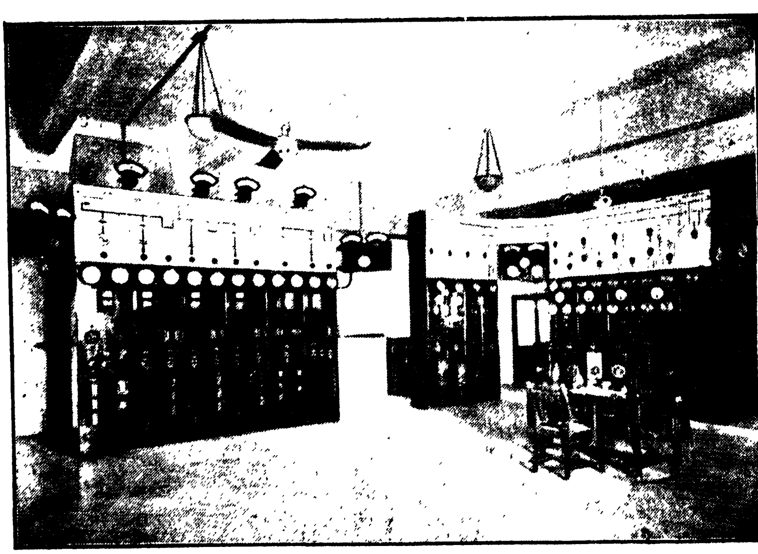

Fig. No. 7. G. I. P. Ry. Kalyan Power House—Control Room.

(Courtesy of G. I. P. Ry.)

gear, out-door step-up transformer station (which is shown in Fig. No. 8)., evaporating plant, oxide film lightning arresters, etc.

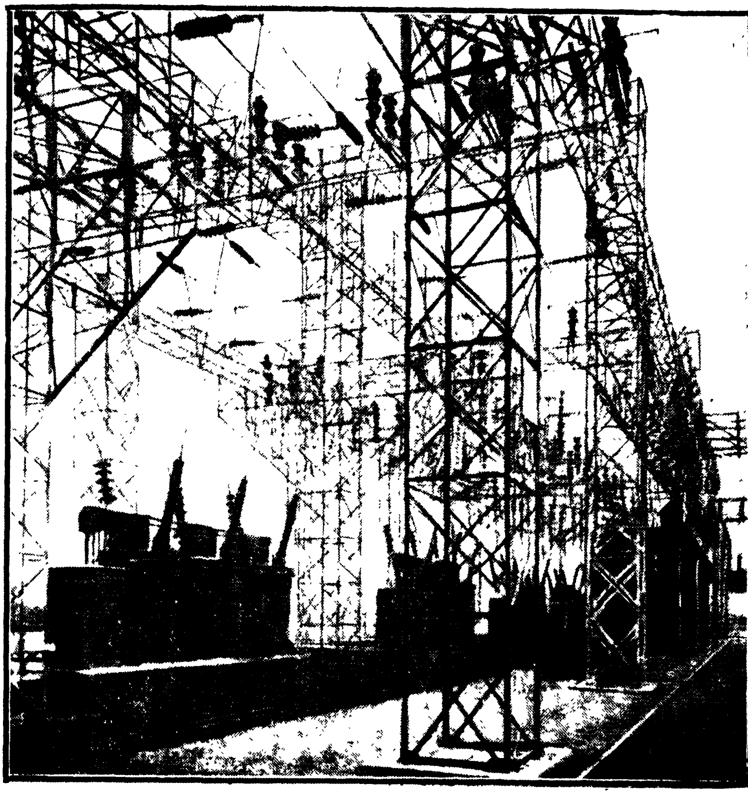

Fig. No. 8. Kalyan Power House—Step-up Transformer Station.
(Courtesy of G. I. P. Ry.)

Transmission System.

The electric power generated at the Power Station is transmitted at 100,000 volts by duplicate overhead lines to 11 rotary converter substations which are spaced about 12 miles apart. The power lines run normally on both sides of the track, suitable precautions being taken to avoid interference with the telegraph and telephone circuits. The total length of the lines is about 270 miles. There are about 2000 towers, each about 70′ high, the normal span being 700′. An additional 8-mile long line (with a span, at one place, of 1750′) has been put up on the Bhore Ghat for use in emergency. Each conductor consists of a stranded aluminium cable with a steel core, the overall area being 0·1 sq. in. Altogether about 840 miles of conductor have been used.

Substations.

Of the eleven substations, five are manually operated, and six are unattended, being remote-controlled by iron-clad draw-out switchgear automatically worked by impulses received through selector relays etc. from an attended station, nearest to the automatic substation. At Thakurwadi, which is nearly midway up the Bhore Ghat, there exists a substation which could not be fed from the 100,000-volt line owing to the physical features of the locality and which is therefore supplied from the Karjat substation by a 22,000-volt line—two special transformers having been installed for this purpose. Ordinarily power is received at 95 to 100 kV over 2 separate lines and the substation plant is protected by hemispherical as well as outdoor aluminium oxide-film lightning arresters, descriptions of which may be seen in I. W. P. P. and 'Lightning Conductors and Arresters'. Pressure is lowerd by 2,750 kVA out-door transformers to about 2 × 560 volts, each secondary winding being connected to a separate 6-phase 1,250-kW 750-V 600-r. p. m. rotary converter. Each oil-cooled power transformer weighs 38·5 tons. For transmitting power for lighting of railway stations and yards, other transformers which raise the voltage from 560 to 2,200 volts are used; they are usually rated at 150 kVA, 6 phase primary and 3 phase star secondary. Insulated underground cables take the power from the substations to the positive terminal of the motor in the train *via* the overhead conductors, circuit breakers etc. and *via* the rails back to the substation.

Automatic Sub-Stations—Plant Installed, etc.

The principal appliances (installed at the Kalyan substation which is the first automatic suburban substation and which feeds power towards Thana, Poona and Igatpuri, in 3 directions) consist of the following, among others :—

Lightning arresters (regarding which the interested reader is referred to the Author's booklet No. III), high-tension iron-clad compound-filled switches, oil-filled transformers (stepping down from 22,000 to 2 × 560 volts), pairs of six-phase 1250-kW 750-V rotary or synchronous converters for supplying direct or continuous current at 1500 volts to the over-head conductors through high-speed circuit breakers and well-insulated cables, auxiliary and station transformers for stepping down to 2·2 kV and 415/220 volts, batteries for lighting and control devices, potential and current transformers, relays for overload, reverse power and phase balance, and overspeed devices. At Kalyan Substation, contactors for starting, running, synchronising

and field reversing, relays for protection against overspeed, hot bearings, alteration in phase rotation, single-phase operation, failure of field excitation and short circuits, etc. were also installed to enable this substation to be converted to remote control.

The 11 main-line sub-stations are located at Vangani, Karjat, Thakurwadi, Lonavla, Kamshet, Shelarwadi (Dehu Road) and Kirkee on the S.-E. line and at Vasind, Thansit, Kasara and Igatpuri on the N.-E. line. The unattended sub-stations are fitted with automatic arrangements worked from nearby stations manned by electricians qualified to operate the electrical equipment. Should the automatic gear fail, provision is made to enable a substation to be operated manually until the defect is cleared and rectified.

Fig. No. 9. Karjat Traction Sub-Station—Control Room.
(Courtesy of G. I. P. Ry.)

Fig. No. 9 shows the control room of the traction substation at Karjat, outside which a loading resistance had been provided to absorb excess of regeneration power. After all the operations for starting an unattended substation have been satisfactorily completed, an indication to this effect is automatically sent to the supervisory station. Otherwise, as already stated, the lock-out relay which can be reset by hand only comes into play. The Kalyan Substation has 'English Electric' automatic switchgear.

Each rotary converter has a continuous rating of 1,666 amps. or of 2,900 amps. for 2 hours or 6,000 amperes momentarily. One of the

special features of these machines is a fan on the armature which forces 10,000 cu. ft. of air per minute through the machine and over the commutator—the air having been first passed through an oil filter. Four of the substations situated at either end of the S. E. and N. E. lines—i. e. at Vangani and Kirkee and at Vasind and Igatpuri respectively—have 3 sets, the others (forming the majority) have 2 sets, each set being of 2,500 kW continuous capacity, 4,375 kW for 1 hour and 7,500 kW for 5 minutes.

Supervisory Control.

In starting an unattended substation from a supervisory control station, a coded train of impulses corresponding to currents of differing frequencies like those of automatic telephones is sent over thin control-line conductors to selectors at the controlled station and operates that selector which is set to the same code as the impulse train, thereby operating the associated link contactor which energises the closing coil of the H. T. oil switch causing the solenoid to operate its plunger to close the switch, a lamp at the control station being lit simultaneously. Whenever on the other hand the switch opens, a second lamp lights at the supervisory station.

Almost simultaneously, audible indications are also given at the Supervisory station. If more than one power switch at the controlled station trips, the indicating impulse trains travel without interference and give the proper indications at the Supervisory station one at a time, but interlocking arrangements prevent the operation of any control by the indicating impulses.

The following paragraphs within inverted commas are extracted, with thanks, from a letter from the General Manager of the G. I. P. Ry. who kindly corrected my MSS. :—

"This selector supervisory remote control system was manufactured by Messrs. Standard Telephones and Cables Limited, England.

The Starting Sequence of Rotary Converters in Automatic Substations Equipped by Messrs. B. T. H. Co. is as follows :—

The high tension isolator and oil circuit breaker are both closed thus energising the main transformer. The control transformer, being connected to the low tension side of the main transformer, is energised and in turn energises the A. C. undervoltage relay which operates and prepares the circuit of the master control contactor. An auxiliary contactor is also energised which operates to open its contacts thus preventing the cumulative series field short circuiting contactor from closing unless regenerative conditions exist.

The master starting contactor remains closed only for a short time and closes the master control contactor. The master controller motor starts and as the master controller rotates the various segments come into contact with their fingers and fix the subsequent operations.

The starting contactors close and connect the starting motors of rotaries to L. T. side of main transformers. The synchronous field contactors close and connect in circuit the fixed tappings of the main field rheostats and auxiliary field of rotary to battery, thus fixing the polarity of the set.

Due to the voltage across the starting motors, the plungers of the synchronous speed relays rise. The rotary convertors accelerate and approach synchronism with correct field adjustment, the auxiliary field having fixed the polarity at which the rotaries build up their voltage. The D. C. polarised relay operates and prepares an alternative retaining circuit for the coil of the master control contactor. The rotaries synchronise and the voltage across the starting motor windings falls off with the result that synchronous speed indicating relays operate and fall after a time interval.

Auxiliary contactors close the running contactors connecting the machines direct to L. T. side of transformer. Now the full field contactors close and connect in circuit the moving arms of main field rheostats. The synchronous field contactors drop out and interrupt the circuits of the fixed tappings of main field rheostats and also disconnect auxiliary fields of rotaries from battery. The equaliser contactor connects the series field windings to the equaliser busbar.

The field relays operate and prepare circuit of the reset contactor for the closing coil of high speed circuit breaker. The starting contactors drop out and disconnect the starting motors from the transformer.

The rotaries are now running direct from the A. C. side, the adjustment of the main field depending upon the setting of the hand-operated main field rheostat.

The reset contactor closes and completes the circuit of the closing coil of high speed breaker. The closing mechanism and interlocks of high-speed breaker operate and allow the main contact of high speed circuit breaker to close, thus connecting the unit to D. C. busbars. Indication to this effect is sent to the supervisory station.

The rotary converter unit continues to run until shut down normally or alternatively by the operation of one or more of the protective devices.

Should the starting sequence not be completed within a given time, the sequence timing relay will complete its timing stroke and

operate, thus interrupting the coil circuit of master control contactor and shutting down the unit. This relay is of the self resetting type however, so that the equipment may be restarted immediately in an attempt to clear the fault."

Current Collecting Equipment

Each of the overhead 1500–V current conductors for the trains, beyond Kalyan, consists of the following:—0·5 sq. in. main catenary wire (catenary being the name of the curve assumed by a freely suspended rope or wire), 0·2 sq. in. auxiliary catenary and 0·3 sq. in. contact wire, giving an aggregate area of 1 sq. in. The overhead line is not above the exact centre-line of the track, but deviates therefrom about 9″ on either side of it, in order that the pantograph may not be worn out on its central portion only but uniformly for about 18″ of its length. The whole equipment is designed for a maximum train collector speed of 80 miles per hour. The fittings used in the attachment and suspension of the conductors are of copper, non-ferrous metal and galvanised mild steel or galvanised malleable iron castings. About 3000 tons of copper were required for the conductors alone. The return path of the current is provided by the rails over which the trains run. The rails are bonded throughout at joints by copper bonds under each pair of fish-plates. On the open line, the structures supporting the overhead equipment are built almost exclusively of broad-flange or H–section beams; whilst in station areas, structures fabricated out of British standard sections are employed. The track structures in the lower Bhore Ghat carry, in addition to the 1500–volt conductors, the 22,000–volt lines conveying a. c. power to the Thakurwadi substation, from Karjat substation. Fig. No. 10 shows the overhead equipment in the yard at Karjat railway station.

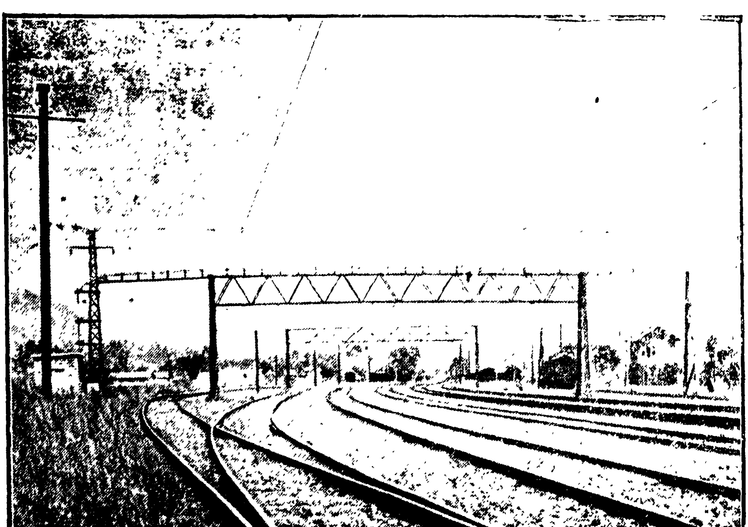

Fig. No. 10. Karjat Station Yard—Overhead Equipment.

(Courtesy of G. I. P. Ry.)

Locomotives.

The Metropolitan-Vickers electric locomotives used here are among the largest of their kind. With steam operation, the goods trains had to be broken up into smaller units at the Karjat Railway Station for the South-East line and at Kasara for the North-East line. No remarshalling is now necessary. With the introduction of electrification, the train reversing station near Khandala on the top of the Bhore Ghat was also done away with, by realigning the track and constructing a 34′ 6″-wide, 24′ 6″-high 5,000-feet-long tunnel of 3 sections (2 long and one short), thereby reducing the time and trouble involved in coming to a halt on the spur and sending the detached locomotive to the other end of the train.† Moreover, wheel slip being absent with electric traction the tunnels are not blocked, as they were sometimes with steam engines whose smoke fouled the pent-up air to a dangerous extent whenever this occurred. Nor is there now-a-days any delay on account of water shortage *en route*.

The goods locomotives, Fig. No. 11, are of the 0–6 + 6–0 or C–C type and have 6 driving axles, there being two trucks with 3 coupled axles to each. The length over buffers is approximately 66 feet, the rigid wheel base is 15′1″, the wheel diameter 48″ and the gear ratio 33/137. There are no carrying axles. The total weight—a little more than 150 tons—is available for driving adhesion The maximum load to be hauled is fixed at 2,000 tons on the level or easy grades between Bombay and Kalyan, 1250 tons when going up grade away from Kalyan and 1,600 tons when going towards Kalyan on way to Bombay. During the monsoon, the maximum load beyond Kalyan is reduced to 1000 tons. The maximum load for 2 steam engines used to be only 450 tons. On the Ghats, two engines are necessary, elsewhere only one suffices. Altogether forty-one goods, and 25 passenger, locomotives are in use. Each locomotive is capable of exerting a tractive effort of 40,000 to 56,000 lbs. (upto 82,500 lbs. on occasions) and gives an aggregate of 2600 horsepower. The normal running speed does not exceed 20·5 m. p. h.; though the maximum safe speed is 45 m. p. h. Each of the two trucks carries a pair of motors geared together on a single intermediate jack-shaft

† *Bhore Ghat Realignment.*

Gradient 1 in 37.88, length of tunnels 4,598′ (longest tunnel 3,103). Length of track decreased by 1,098′. New 115 lbs. flat footed rails with base plates instead of 100 lbs. New alignment, 2.11 miles. Tunnel section, 34′ 6″ wide and 24′ 6″ high. Believed to be the longest tunnel section in the world cost Rs. 60 lakhs. Excavation 95,00,000 c. ft. of which 76,00,000 c. ft, was rock. Time taken–17 working months. Contractors—Hindustan Construction Co.—*vide* (Burford's article in Silver Jubilee Memorial Volume, Dec. 1939, Bombay Engineering Congress).

from which the power is transmitted to the wheels by means of connecting and coupling rods; the latter enabling satisfactory

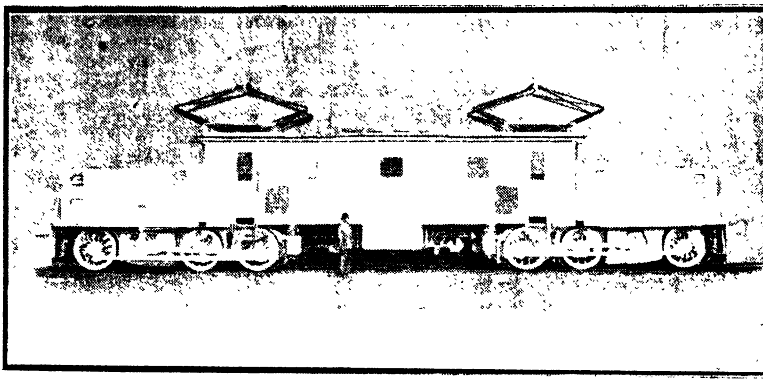

Fig. No. 11. Electric Freight or Goods Locomotive.
(Courtesy of G. I. P. Ry.)

running in 4 ft. flood water. Each of the 4 motors is 650 h. p. A special feature of the locomotive-motors is their capacity for regeneration. This assists in taking trains down steep gradients economically, efficiently and safely. The motors become, for the nonce, generators being driven by the wheels rotating due to the energy supplied by the train rolling by force of gravity, and supplying current to the mains instead of consuming it, when travelling down hill. Each engine can exert a retarding effort up to 70,000 lbs. Besides regenerative braking, ordinary braking is used : for the trains the vacuum system and for the loco. the compressed-air system is employed.

The total weight of each passenger locomotive (Fig. No. 12, type 2–6–4 *or* 1 A A A 2 *or* 1 C. o. 2 (see footnote),* speed 70 m. p. h.) is 105 tons, of which 60 tons hangs on the three driving axles. The length over buffers is 53′ 6″ and the rigid wheel base is 7′ 6″; the latter being the distance between two consecutive axles. The driving wheels have a diameter of 63″ and the carrying wheels 43″; the gear ratio being 1 : 3·66. Each engine has 6 motors, 425 H. P. each. There are 2 driving cabins, one at each end of the engine, with a corridor between them. The control is electro-pneumatic. All the high-tension switchgear is in a chamber in the middle of the engine. The door of the chamber is inter-locked so as not to be opened unless and until the pantograph is down. Figs. Nos. 11 and 12 show the freight (or goods), and passenger, locomotives respectivly.

* The number denotes carrying axles, the letter denotes driving axles and the index 'o' is inserted after the letter in case of individual axle drive.

For the passenger engines, regenerative braking is not provided, as freight locos. only are employed for the Ghat section and the

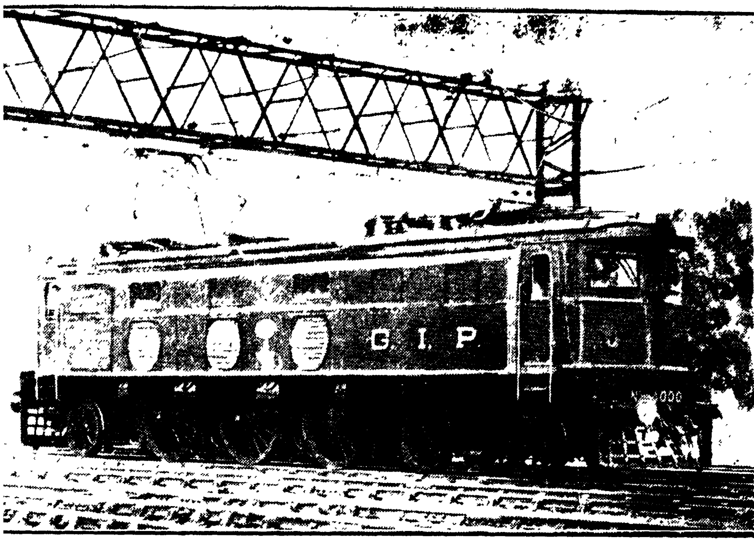

Fig. No. 12. Electric Passenger Locomotive.
(Courtesy of G. I. P. Ry.)

Vasind Bank. Although asymmetrical, having 2 axles at one end and only one at the other end, the passenger engine ran smoothly and without oscillations even at speeds approaching 80 miles per hour, while under test. As stated above, prior to electrification, 2 engines were needed to haul 450 tons over the Ghats and 3 for 650 tons ; the speeds being between 8 and 13 miles per hour. The electric traction load is fixed at 1,000 tons for 2 locomotives, the speed varying from 18 to 21 miles per hour up the Ghats. When descending the Ghats, regenerative braking helps in reducing the consumption of power and the wear and tear of brake shoes and wheel tyres.

Auxiliary Apparatus on Locomotives.

The Auxiliary apparatus on the locomotives described above includes the following :—

Machines. Blowers and armature-fans for ventilation of traction motors ; motor-generator, consisting of a 1400 V motor and a 2 kW, 50 V generator ; a battery of accumulators ; two rotary exhausters, each of a capacity of 242 cu. ft. per minute ; a reciprocating compressor, capacity 38 cu. ft. per minute.

Equipment. Cast iron resistances ; controller ; contactors, operated electro-pneumatically ; cams for operating switch groups

and reversers ; expulsion and cartridge type fuses; field-tap contactors for reducing the excitation and increasing the speed. N. B. The pantographs are operated by compressed air.

Locomotive Sheds

At the terminii of the main-line electrified sections and of the Bhore and Thull Ghats, viz. at Kalyan, Karjat, Lonavla, Poona, Kasara and Igatpuri, electric locomotive sheds have been provided for the purposes of cleaning, repairs and overhaul—the latter operation requiring the most careful inspection of the following :—main and auxiliary motors, axle generators, unit and group switches, resistors, compressors, exhausters, pantographs, jackshaft and axle bearings crankpins, big-end and side-rod bushes, wheels, tyres, axles, main springs, spring hanger cotters, equalizing pins, gears, pinions, etc.

For the training of drivers of locomotives, the Kalyan shed, yard and lines are suitable : and for drivers of multiple-unit stock, the Kurla Car Shed is fitted for instructional purposes.* A course of six-months' duration ought ordinarily to suffice for those who have had some preliminary training or those who have been driving steam locomotives. Statistics, relating to electrification, taken from the Annual Report of the G. I. P. Ry. may be seen in the last chapter.

There are no electric locomotives specially built for shunting service, or locomotives driven by batteries, in use on the G. I. P. Ry. as is the case on the B. B. & C. I., and S. I. Railways. Other contrasts between this Trio of Electric Railways in India may be seen summarised and tabulated in Appendix VI.

The Central Provinces Pench River Project (see '*Hydro-electric Stations of India*') could, if carried out and completed to furnish the power expected from it, provide sufficient electrical energy for the electrification of the G. I. P. Ry. from Igatpuri to Bhusaval, for a portion of which, however, power could be had from the Bhandardara Dam Hydro-electric Plant (see '*Indian Water Power Plants*' pages 69 and 71) which is likely to be put up by the Bombay Government, as soon as normal conditions return after the close of the War recently begun. The extension may be made in stages, to Manmad, Nandgaon, Chalisgaon, Pachora, Jalgaon and Bhusaval.

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* In his model railway, Mr. H. J. Mulleneux, Chief Electrical Engineer, has provided an excellent means of enlightening, those anxious to learn, by demonstrating the lay-out and working of electric railways. The model comprises two extremely elaborate control cabins, stations for passengers, bridges, roads, buildings, over-head line and signal equipments, out-door transformer station, models of G. I. P. R. locomotives and suburban units, of celebrities, railway institutes, grounds, points, crossings, switches, signals, tracks, interlocks, relays, indicating lamps, illuminated diagrams, buffers, disconnectors, platforms, ghat roads, etc., etc.

CHAPTER V.

B. B. & C. I. RAILWAY ELECTRIFICATION.

:o:

FIRST INSTALMENT.

1. Introductory Remarks.

The Bombay, Baroda and Central India Railway have carried out the electrification of their Bombay Suburban section in two instalments. The first instalment was begun in 1926 and carried out to completion, at a cost of about 2 crores of rupees, on January 5, 1928 for a distance of 22½ miles of the B. G. i. e. 66″ or broad-gauge system from Colaba to Borivli — all running tracks between Colaba and Bandra, and the Up and Down Local tracks between Bandra and Borivli, being converted to electrical working. In 1930, the new main-line terminus, with a power frame for 30 colour light signals, at Bombay Central, between Grant Road and Mahalaxmi Ry. Stations and near Bellassis Bridge, having been completed, Churchgate was made the terminus for the suburban service and the section from Colaba to Churchgate — a distance of 1¼ mile — was dismantled. The mileage electrified came to about 57 track miles. Although the suburban service has from the beginning extended upto Virar, in the first instance the section terminating at Borivli was electrified as the traffic over the sixteen miles between Borivli and Virar was so light as not to justify the expenditure involved in conversion to electrical working. The track from Grand Road to Borivli is quadruple. Termination of the electric trains at Borivli meant trans-shipment of passengers etc., and the employment of steam shuttle trains. This has now been rendered unnecessary by completion of the second instalment of electrification

N.B.—The Ms. of this chapter was kindly perused and corrected by the Chief Electrical Engineer, B. B. & C. I. Ry., and the photographs and diagrams illustrating it are reproduced with thanks from the publications of the B. B. & C. I. Ry. and of the Bombay Engineering Congress. Fig. Nos. 14 and 15 are from Mr. N. N. Iengar's Paper before the latter body ; Fig. 15 having been slightly modified as explained at the end of the chapter.

The distance between stops is approximately as follows:— 1 mile between Churchgate and Andheri, 1½ mile between Andheri and Kandivli, and 2½ miles between Kandivli and Virar. The necessity for the abandonment of steam working in favour of electrical traction will be realised from the following figures for the number of passengers carried in years prior to electrification :—10 millions in 1888, 24 millions in 1914, 30 millions in 1918, 45 millions in 1922 (but this was the boom period after the War), 38 millions in 1928 when electric traction was introduced. Fig. No. 2, adapted from the map printed along with the paper read before the Bombay Engineering Congress by Mr. N. N. Iengar, shows the suburban electrified lines of the B. B. & C. I. Ry.

2. System of Power Supply.

The electric power required for running the electric trains is supplied by the Tata Trio of Water-power Plants situated at the foot of the Western Ghats at 3 different places, through their receiving stations at Kalyan and at Dharavi near Matunga (Bombay): detailed descriptions and illustrations of the latter can be seen in the Author's books entitled " *Hydro-electric Stations in India* " and " *Indian Water Power Plants* ". Supply is received at 22-kV 3-phase 50 cycle at three sub-stations of the B. B. & C. I. Ry. Co., situated at Grant Road, Bandra and Kandivli which are 2,9 and 19½ miles respectively from the Churchgate Railway Station, see left side of Fig. 2. The Ry. Co. have their own separate duplicate feeders for this 22-kV supply, consisting of 0.2-sq. in underground cables to the sub-stations at Grant Road and Bandra, and 0.15 sq. in. overhead stranded-copper conductors from Santa Cruz to Kandivli — the portion from Bandra to Santa Cruz being of the same sectional area but placed underground. The overhead conductors are suspended through suitable insulators from cross-span wires fixed to steel structures supporting the D. C. 1500–V line supplying current to the electric trains, as well as the subsidiary 2.2-kV line supplying electric power for lighting the stations and yards and for auxiliary purposes; from the 2.2-kV line, a 110–V supply is provided by step-down transformers for the purpose of signalling by power.

3. Railway Substations.

The 22-kV a. c. supply is reduced in voltage to 565 volts at the railway substations by static transformers so as to be supplied to sets of rotary converters which change it to d. c. at 1500 volts for

the overhead contact wire of the train service. The Grant Road and Bandra sub-stations have 3 sets each, and the Kandivli substation

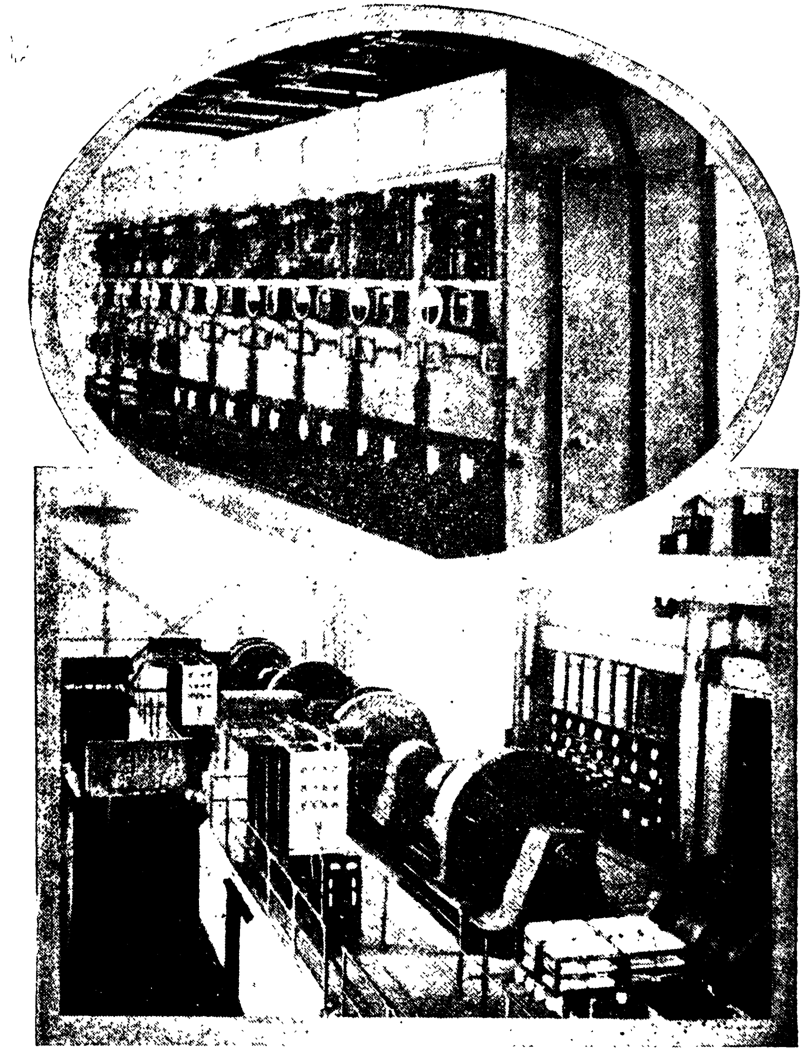

Fig. Nos. 13 and 13 (a). Two views of interior of *Bandra Substation*, showing (1) Switchgear and (2) Converting Machinery.
(Courtesy of B. B. & C. I. Ry.)

has 2 sets. Each set consists of 2 separate rotaries rated at 1,250 kW 750 V, the two machines running in series providing the 1,500-V supply. The total normal capacity of the three substations amounts to 20,000 kW. The substations can be worked either manually or

automatically; under the latter method all switchgear and sets can be operated by means of impulses from the Power Supervisory Control room in an office near the Bombay Central Railway Station, nearly 17 miles from Kandivli. Necessary protective apparatus for regulation and protection is provided at each of the substations and the two track-sectioning cabins at Elphinstone Road and Andheri. The average power demand for the Churchgate-Borivli section has been about 8,000 kW (15-minute Maximum) as measured at the Dharavi end of the supply: the annual consumption of energy came to 30.6 millions of kilowatt-hours, momentary peak loads being 16,000 kW during the rush hours in the mornings and evenings. The kilowatt-hours purchased during 1938-39 amounted to 31,825,907. The substations contain the following equipment (to mention only the most important items):—

(*a*) Switchgear—Iron-clad 22-kV switchgear for the feeders converters and lighting-transformers; 2·2-kV iron-clad switchgear for the station-lighting distributors; 1.5-kV d. c. switchgear for the traction feeders; 400-V and 110-V switchgear for the auxiliary supply and for automatic gear for starting the rotary converters.

(*b*) Rotary or synchronous converter Sets.—These comprise 22000/565 x 2-volt oil-immersed transformers and series-connected, converters for changing to direct current at 1,500 volts.

(*c*) Subsidiary transformers.—Besides the traction transformers used with the rotaries, there are 22000/2200-volt and 565/440-volt transformers for station lighting and substation auxiliary purposes respectively (The latter type have a tapping at 110 V).

(*d*) Secondary or storage Battery.—There is a 110-volt battery for emergency lighting and d. c. supply for relays, contactors and tripping coils: for charging the battery, a motor-generator is installed.

Figs. Nos. 13 and 13 (*a*) depict (i) switchgear and (ii) converting machinery, inside the Bandra substation.

4. Overhead Traction Supply.

The overhead contact wire is of 0.25 sq. in. and is supported by droppers from a stranded-copper catenary wire of 0.375 sq. in., giving a conducting area of 0.625 sq. in. per track. The catenary wire is suspended through double insulators from latice-steelwork structures spaced about 220 ft. apart normally. The return circuit is provided

by the track rails and negative feeder cables. The contact wire is prevented from being blown away by the wind by means of a 'register-arm' attached to a cross-span wire. Where curves occur on the railroad, the contact conductor is kept over the centre of the track by means of pull-off wires insulated at the supports and connected to it and to the catenary conductor. At certain points, sectionalising switches have been inserted in the overhead conductors to enable faulty sections of the line to be disconnected, examined and repaired.

5. Electric Rolling Stock.

An electric train consists of 7 coaches, of which two are motor coaches, each equipped with 4 d. c. ventilated 750-volt series motors —two motors being connected in series across 1,500 volts—which together give 1100 H. P. i. e. sufficient power to accelerate a fully-loaded train of 400 tons at the rate of 1 mile per hour per second or, in other words, to enable the train to reach a speed of 30 m. p. h. in 30 seconds. The 7-coach train has a free running speed of 52 miles per hour. Such a train can accommodate 1289 passengers. Each coach is 68 feet long and 12 feet wide, and is fire-proof, being all made of steel. Each motor coach has a 1,500-volt or high-tension compartment which contains isolating switches, line breakers, relays, resistances, cut-outs, auxiliary sets and control equipment.

Two 55-ton battery locomotives—the largest in the British Empire-were supplied in 1928 by the English Electric Company : in the same year, colour light signals were put up at Marine lines and Charni Road Ry. Stations.

SECOND INSTALMENT

To avoid the trouble of changing over from electric to steam traction at Borivli and the necessity for further expenditure over renewals of rolling stock and steam engines, and to effect economy which would be ensured by through running of trains, the Railway authorities extended the electrified section from Borivli right up to Virar in 1936 when the double-circuit 22kV lines from Thana to the new substation at Bassein Road were erected and put into use by the Tata Power Company. The traction substation at Bassein Road is 32½ miles from Churchgate but the service extends five miles beyond Bassein Road, making a total route distance of about 37 miles (actually 36·79 miles), and a track distance of 91·58 miles, electrified to date. The average distance apart of the substations is about 10 miles, see Fig. No. 2.

1. Power supply to Bassein Road Substation.

The power lines to Bassein Road Substation are tied with the Kalyan-Thana 22-kV lines through 2 group-operated air-break disconnecting switches, a paralleling bus (22-kV) and a group-operated air-break tie switch at Thana outdoor switching yard which is close to the G. I. P. Ry. traction substation and is attended continuously for testing and maintenance operations. From the switching yard to a distance of 1-1/3 miles, the lines are supported on latticed steel towers. This portion of the power lines crosses the G. I. P. Ry. main lines out of Bombay. Between the railway and road bridges, the power lines run in the middle of the Thana Creek so as to keep away from the boat traffic of Kalva Bunder where a 90′-navigation-clearance has been provided. The towers are founded in mud with tide-water level variations of 13′ (max.). Two dead-end type single circuit towers are used to connect this portion of the line to the adjoining pole lines—the conductor tensions being greater than elsewhere. Pole construction is employed for the next seven miles upto Bassein Creek Crossing at Gaimukh where conditions for crossing are favourable. At this place, four special 74′-high single circuit towers are erected, the span being 1580 feet. The towers are located on the hill sides 70′ and 76′ above high-water level and provide a minimum navigation clearance of 92′ above high water. They are held by reinforced-concrete block anchors resting on firm soil or rock. On account of the long span, the conductors are arranged horizontally 13½′ apart. A clearance of 50′ between the two circuits has been provided. One of the towers carries the telephone circuit and the other an overhead ground wire for protection against lightning, in addition to the three power conductors.

From Gaimukh Crossing, the lines are again carried on poles. For a distance of 2¾ miles from Gaimukh, they pass through very rugged country covered with dense jungle and government forests. Two more creeks are crossed before Bassein Road is reached. At Hiragar Creek (1. 3 miles from Bassein Road), a double-circuit latticed steel tower with conductors mounted in suspension, see Fig. No. 14, was used to give an overall clearance of 79′ above high-water level—20½′-long reinforced-concrete pier supports being necessary for this tower which rests wholly in clay. The last creek crossing is at Sopara, ½ mile from Bassein Road, where 90′ clearances above high water level are provided by tower and pier construction, similar to those for the Thana Creek Crossing. At Bassein Road Substation, the lines are dead-ended on separate latticed steel towers,

designed for mounting group-operated disconnecting and grounding switches at the top to isolate the lines from the substation. The Railway Company's substation plant is connected to the supply lines at the terminal towers by 3-core armoured cables, approxima-

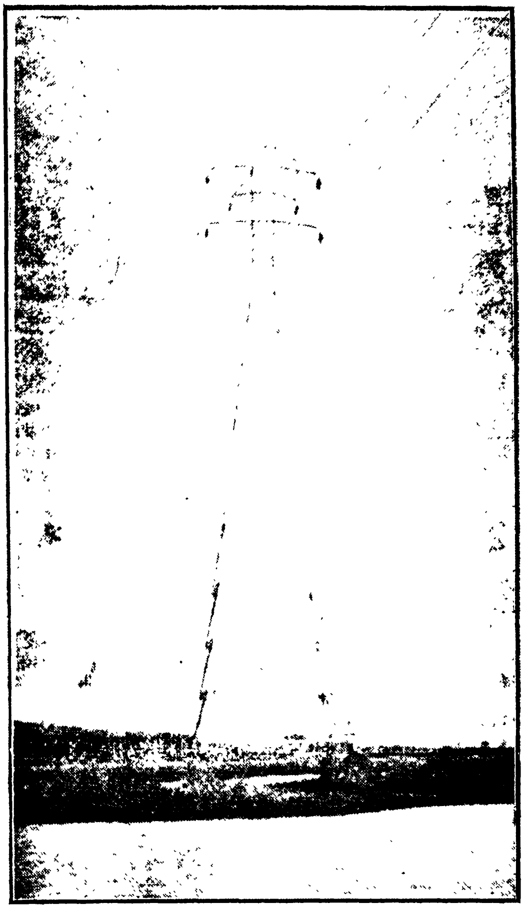

Fig. No. 14. Hiragar Creek Crossing Tower.
(Courtesy of Bombay Engineering Congress.)

tely 500′ long. The complete route length of the lines is $19\frac{1}{2}$ miles, of which 2·2 miles are of steel tower construction and 17.3 miles are on poles.

2. Protective System.

At the supply end, *viz.* at Kalyan Receiving Station, the parallel feeders are protected by a high-speed balanced ground current relay with straight induction type inverse time-limit overload relays in

the phases for back-up protection and for single-line operation. At the receiving ends, viz. at Thana and Bassein Road Railway substations, the feeders are protected by induction type reverse-power overload relays in the phases. The Thana Railway Station 22-kV buses are sectionalised by an automatic oil circuit breaker. To avoid a complete shut-down of the station in the event of 22-kV station faults, ground-current differential protection between the different 22-kV circuits has heen provided at the Thana Railway substation. The high-speed current balance relay at Kalyan Receiving Station operates in less than a cycle during line faults. As this speed of operation would not conduce to selectivity with the fuses used for several auxiliary supplies served by one of the lines at a time, induction-type overload ground-current relays are used in series with the high-speed relays to introduce an adjustable time delay, to enable the fuses to operate first. The co-ordinated protective relay system (see Fig. 15 and its explanation at the end of this chapter) has been functioning satisfactorily to isolate the faulty line only at all ends during the fault.

3. Bassein Road Substation.

The Bassein Road substation started regular operation on September 1, 1936. The 15-minute maximum demand was 1,300 kW in October, 1936. Momentary power demands when starting trains have been of the order of 4,080 kW. Instead of rotary converters, two 2,000-kW glass-bulb type mercury-arc-rectifiers (one of them spare) have been installed at Bassein Road Substation, this substation being designed for manual operation. The principal items of equipment installed in the Bassein Road Substation are as follows :—

(*a*) Switchgear.—Same as described already under the heading " 3. *Railway Substations.* First Instalment ".

(*b*) Two rectifier sets, comprising 12-phase 22000/1590-V oil-immersed transformers with glass-bulb type grid-controlled mercury-arc rectifiers for converting a. c. to d. c. at 1500 V. Each set consists of six 6-phase glass bulbs, divided into two banks of three across six phases. An Isenthal auto-voltage regulator is also provided.

(*c*) Subsidiary Transformers.—22000/2200-volt for supply for station lighting, and distribution at 2·2 kV.

(*d*) Battery.—A battery of 110 volts is provided for emergency lighting and for d. c. required for relays, contactors and trip coils. To charge this battery, a glass-bulb rectifier is installed.

(*e*) *Harmonic Suppressing Device.*—This consists of one main reactor, and filter circuits (consisting of inductor and condenser) tuned for 600 and 1200 cycles.

4. System of Supply.

The substation and overhead and track equipment as also the facilities to supply power to the substation were all provided within costs that help to secure economies for electrification as compared with steam engine operation. The 22-kV lines to Bassein Road substation come direct from Tata's Thana-Kalyan 22-kV system. Alongside the track, fabricated lattice, and workshop-made special railbuilt, steel structures support the 1500V D. C. line equipment as well as the subsidiary 3-phase 50-cycle 2·2-kilovolt supply for lighting the stations and yards and for signalling purposes, on the Borivli-Virar section. Distribution of supply is partly overhead, partly underground. The overhead contact wire is of 0.25 sq. in.—but at some places 0·3 sq. in. is used to obtain longer life and better conductivity. It is supported by droppers from a stranded-copper catenary of 0.375 sq. in., giving an area of 0·625 to 0.675 sq. in. per track. The catenary wire is suspended in station yards from lattice steel work structures, but over the major portion of the section the track structures are rail-built ones manufactured in the Railway Workshop. Cantilever structures with extension brackets are used for single-track work.

5. Electric Train Equipment.

Current at 1500 volts D. C. is conveyed from the overhead conductors to the driving motors through the pantograph collectors and control apparatus, and is led back to the substation *via* the track rails and negative feeder cables. These rails are copper-bonded to reduce the resistance of the main circuit so that most of the current returns and very little goes astray under the ground, thus lessening the risk of damage by electrolysis. There are 40 passenger motor cars, each of 71 tons and 1,100 h. p. Over each motor coach, see Fig. No. 16, there are lightning arresters in the circuit to the isolating switch in the H. T. compartment. There are two pantographs, one at each end, connected through choke coils and worked by compressed air on piston rods of two cylinders. The lightning arresters are of the magnetic blowout type and two of them are connected in series across line and earth. Batteries are fitted in the driving compartments of motor coaches for supplying current for emergency lighting purposes in case the main power supply fails. The motor-generator is a 10-kW compound-wound machine designed for self regulating voltage; it reduces the pressure from 1500 to 110 volts and its current is primarily meant for fans, lights and control devices. The main traction motors suspended under each motor coach are 4 in number, 275 H. P. (one hour basis) each and provided with interpoles and tapped field (1500/700 volts). The compressor is driven by a 4¾ H. P. motor and is used for operating the pantographs, whistles etc. Its governor is set so as to start the motor when the pressure of the air falls to 75 lbs. per sq. in. and to stop the motor when the pressure exceeds 90 lbs. per sq. in. The vacuum-exhauster is of the rotary type and is driven by a 7-H. P. 1400-V 1550-r. p. m. motor provided with tapped-field windings for 2 speeds; at the lower speed of 850 r. p. m. the horse power is 3.84,

which is enough for maintaining the vacuum once it has been created and established at 20″.

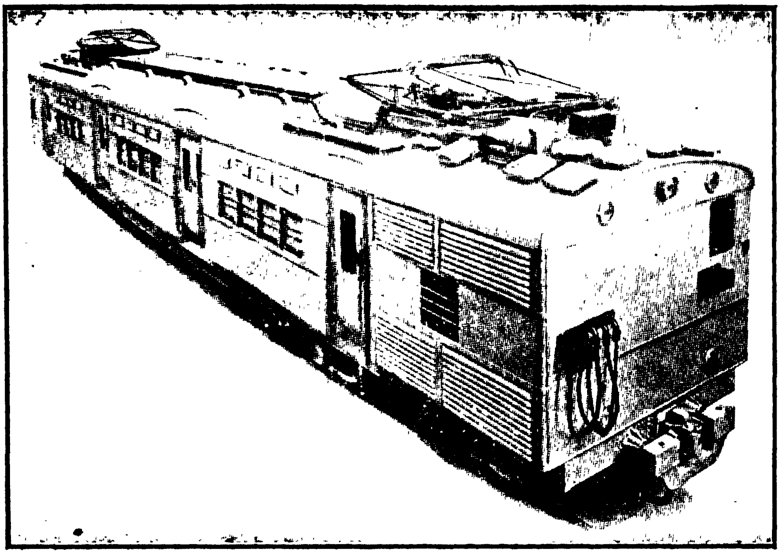

Fig. No. 16. B. B. & C. I. Ry. Motor Coach, showing pantograph collectors.
(Courtesy of B. B. & C.I. Ry.)

The driving cabin of a motor coach contains the following accessories :—Master controller, driver's brake valve controller, control switches (including multiple-contact control cut-out), pantograph operating switch, reset switch for overload relay, set and trip switch for lighting relay, switches for remote operation of lights. In the driving cabins of trailers, the multiple-contact control cut-out is omitted but a main fan circuit switch is provided.

"The bodies of the coaches are made of plates, rolled sections and pressings securely rivetted together. The method adopted for building up the sides is one which has been patented by the suppliers, Messrs. Cammell Laird & Co. The design allows for the free circulation of air between the inner lining and the outer shell, efficient insulation being thereby provided; whilst condensation which is so often the cause of corrosion in enclosed spaces has been entirely eliminated.

The coaches are provided with wide sliding doors constructed of aluminium alloy suspended on 'Crittal' runner bars with guides at the bottom working in grooves formed by the sill plates. Wind screens are provided for each door way and there is a vertical hand-pole in the centre of the coach. The buffing and drawgear is of the M. C. B. pattern, and smooth running is ensured by suitably sprung cast-steel bumpers. The interiors of the coaches are lined with teak throughout — upper class seats are of the 'nesta' type.

The complete electrical equipments for the coaches was supplied by the B. T. H. Co.. Ltd. The motors have been designed to be water-tight (as the track is flooded during monsoon period), and solid covers are provided to replace the open covers over the air inlet and outlet during this period.

Owing to their exceptional size, the coaches could not be consigned by rail without being dismantled and were therefore conveyed by water to Hull from the Works at Nottingham."

6. Precautionary Arrangements.

As the H. T. compartment contains many appliances operating at high voltage (1500 volts), the doors of this and adjacent compartment are so interlocked that power can not be switched on, unless and until these doors are closed, to the main and auxiliary H. T. control apparatus through the main isolating switch. Conversely, power must be switched off from the line before access can be had to the H. T. compartment.

The motorman in the driving cabin who has to manipulate the master controller can not come in contact with the 1500-volt appliances. He is enabled to concentrate attention on the signals on account of the automatic acceleration of the train provided for by the control apparatus. The master controller is fitted with a "deadman's switch" and a pilot valve for emergency operation of the brakes when the motorman is disabled for some reason from doing so.

Power cabins for colour light signalling have been provided at Bombay Central (1930), Churchgate (1931), Mahim and Bandra (1935) and for the Borivli-Virar section (1937-38).

LOCOMOTIVES.

Besides the two battery locomotives which are used by the B. B. & C. I. Ry. at Carnac Bridge, this Railway Company possesses two Diesel-electric locomotives equipped with Armstrong-Sulzer engines and English Electric switchgear, motors etc., in use at Bandra Marshalling Yard and at Dohad Workshop, where overhead electric traction lines do not exist. Dohad is 334 miles away from Bombay Central and the Locomotive Works there cover 840 acres of land; the workshops handling all repair work for the Company's broad-gauge locomotives and rolling stock. The following particulars pertain to the shunting locomotives :—number, 2; weight, 54 tons each (1 ton of 2,000 lbs.); tractive effort 29,000 lbs. maximum, and power–228 h. p., per loco.

Details relating to diesel-electric railcars and locomotives may be seen in Chapter VII, and additional statistics *re* electrification, etc., in Chapter XII.

Explanation of Fig. No. 15.

This figure is a large-sized Plate, of a single-line diagram of an a. c. 3-phase supply transformed and converted to d. c., showing the co-ordinated protective relay scheme for the 22-kV line and sub-station faults on the Kalyan-Thana-Bassein Road 22-kV transmission system, supplying the Thana and Mulund City Sub-Stations (and G. I. P. and B. B. & C. I. Railways through the Thana and Bassein Traction Sub-Stations) from the Tata Hydro Power Company's Receiving Station at Kalyan.

In order to keep the diagram clear of an excess of lettering, the following abbreviations have been employed :—M. A. R.—Mercury Arc Rectifier ; T. S.-S....Traction Sub-Station ; A. S. T.—Auxiliary Service Transformer ; B. C. O. D....Bus Coupling Oil Disconnector ; kV......kilo Volt ; L_1 ....Line 1 ; L_2 ......Line 2 ; P. D. I. O. R....... Phase, Directional, Induction type, Overcurrent Relay ; P. B. O. R.... Phase Balance Overload Relay ; R......Relay ; A. P. C. R.......Automatic Potential Changeover Relay ; PTs...Potential Transformers ; small circles represent Relays, small rectangles Oil-Circuit Breakers (O. C. B.) ; V...Volt ; A...Ampere : S....Switch (to be closed one at a time) ; O. F.......Overhead Feeder ; S. F....Switch Fuse (only one to be closed at a time) ; D. S. (o)......Disconnecting Switch (normally open) ; D.S. (c).. ..Disconnecting Switch (normally closed) ; C.S.S.-S.... City Supply Sub-Station : a, a_1......Auxiliary Switches, Open when O. C. B. is open and closed when O. C. B. is closed ; a_1 should be timed to open few cycles earlier than the parting of the main breaker contacts ; Tc...Trip Coil:-ve...Negative; + ve...Positive ; CTs...Current Transformers ; I. D. I. O. R.......Inverse-time and Definite-time limit Induction-type Over-current Relay ; 3...Three : I. D. I. E. O. R....... Inverse-time and Definite-minimum time-limit Induction type Earth-leakage Over-current Relay ; 25 p. c. U. H. G. R.......25 p. c. Unbalance High-speed Ground-current Differential Relay ; B. W. S-S.......Braithwaite Workshop Sub-Station : P. C. R.......Potential Changeover Relay ; 3ϕ...3 phase ; D. P. O. R....Directional Phase Overcurrent Relay ; D. G. O. R.......Directional Ground Overcurrent Relay ; T. W....Tertiary Windings ; s...sectionalising circuit breaker in Bus bar ; I. D. I. D. O. R....... Inverse-time and Definite-minimum time-limit Induction-type Directional Ground Overcurrent Relay ; I. H. A. R.-Instantaneous Hand-reset Auxiliary Relay (This relay trips Breakers L_1 and s) ; I. H. A. O. A. R....Instantaneous Hand-reset Adjustable Overcurrent Auxiliary Relay for tripping Breakers L_2 and s) ; T_1 and T_2 ...Breakers for A. S. T. : R_1 , R_2 and R_3 ...... Breakers for R. C.s ; R. C.......Rotary Converters ; Ex. R. and I.... Existing Relays and Instruments : T. C. T. (1)...Totalizing Current Transformer 1 ; multiple primary, single secondary, primary windings designed and connected differentially so as to give zero current in secondary winding under normal conditions : T. C. T. (2)......Totalizing Current Transformer 2, for differential protection scheme for 22-kV Bus faults in the Sub-Station ; A. S. T....Auxiliary Service Transformers.

at the Egmore substation from the Madras E. S. Co.'s Power House and is converted by large steel-clad Mercury Rectifiers into 1500-volts D. C. which is supplied by overhead lines to the electric locomotives and coaches. Provision has been made for permitting trams to cross the railway lines (see Fig. 19) as well as for removal of certain overhead lines to allow high Raths or Tazias to pass at certain seasons when Hindus or Mohammedans respectively celebrate events of a religious character on a large scale in public. Fig. 18 shows the 1500-V line-feeding arrangement and Fig. 19 the Railway-tramway electric lines crossing arrangements.

Electric Rolling Stock.

It is of special interest to note (comments the writer of the English Electric's Railway Series, Nos. 51 and 56, from which the following account is quoted with thanks) that the scheme involved not merely the conversion of existing steam-operated lines to electric working but included the construction of new tracks and stations to accommodate suburban traffic that had increased so much as to impede the main line services. Certain shunting yards of Madras have been electrified so that shunting operations and freight services can be carried out with electric locomotives. The first order was for 17 three-coach articulated units, each consisting of one motor-coach and two trailer coaches; and 4 locomotives with 2 battery-tenders. "The motor-coach units are arranged for multiple-unit working, so that trains may be made up with three, six or nine coaches, according to traffic conditions. The electrical equipment has been designed to give an average speed, with a fully-loaded train, of 40 miles an hour over the whole distance,—station stops being 1·5 mile apart.

A 3-coach unit is carried on four bogies and the power equipment consists of *four* 120-h. p. motors connected in pairs in series. The motors are of the self-ventilated type, but owing to the extremely dusty conditions the ventilating air is drawn from inside the coach through ducts and sliding flexible joints.

The control equipment, on the English Electric Co.'s all-electric camshaft system, is housed in a compartment at one end of the centre coach, which also contains a 4-kW motor-generator set for supplying the control and lighting circuits and a motor-driven rotary exhauster. All air entering the compartment passes through filters contained in the walls. The control circuits are supplied from the motor-generator set at 60 volts and an emergency battery, which is charged automatically, floats across the terminals of the set.

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Of the 17 units supplied in 1931, 10 were composite 1st., 2nd and 3rd class, arranged to suit the local customs and conditions, and the remaining 7 were 3rd class units. The seating capacity of a 3rd class unit is 194, and a unit is 151 ft. long and weighs 73 tons. The four 0-4-4-0 or 0-B-B-0 electric locomotives have articulated bogies, each equipped with two nose-suspended axle-hung 160-h. p. motors. As in the case of the motor-coaches, the ventilating air is drawn from the interior of the vehicle which has air inlets with filters. The control equipment is mounted in a compartment at the centre, and the driving apparatus is provided at each end."

Locomotives.

"The electrical equipment of the locomotives is generally similar to that of the motor-coaches, with the exception that it is not arranged for multiple-unit operation and that three running positions are provided in series and parallel by means of weakened-field notches. The locomotives are capable of hauling 500-ton freight trains, or 250-ton passenger trains, at speeds of from 25 to 40 miles per hour; they have a length over buffers of 32 feet, a width of 8 feet 6 inches and a weight of 42 tons. Braking of the units themselves is by compressed air, but vacuum brake gear is fitted in addition to suit the existing rolling stock.

One of the chief difficulties encountered in laying out this electrification was the fact that there were a number of small yards at some distance from the main line which could not conveniently be provided with overhead construction and at the same time it was extremely undesirable to have to provide a steam locomotive whenever movements had to be carried out at these yards. The problem was solved by providing in addition to the locomotives two Battery-tenders equipped with heavy-duty batteries, capable of supplying the locomotives at 440 volts. When a locomotive is required for service of the kind indicated, one of these tenders is attached to it and after the limit of the overhead construction has been reached the pantograph is lowered and by changing over a single switch, the locomotive runs on the 440-volt supply from the battery.

These tenders, which weigh only 21 tons, have a capacity of 158 kW-hours at the five-hour rate of discharge of the battery. A complete charging switchboard and auxiliary air-brake compressor, operating at the lower voltage, are carried on the tender": see Fig. No. 20.

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electric motors are on the centre coach, the other two coaches being trailers. Welding was employed for the joints of the underframe and the bogie members, whilst many other parts were welded instead of utilising steel casting. The saving in weight was very considerable, amounting to over 2½ tons for the trailer body and underframe alone.

Substations, Overhead and Driving Equipments.

The 3-storey static substations are designed to suit the climate of the south-east coast and to replace the heated air by fresh cool clean air continuously. They contain H. T. circuit breakers, switchgear, transformers, rectifiers etc.: a control board at Egmore substation enables the operator to effect control from a distance as the various connections are indicated by small lamps and by bells.

As shown in Fig. No. 18, the Egmore Controlling Substation receives power at 5000 volts, 3 phase, A.C. from the Basin Bridge Steam

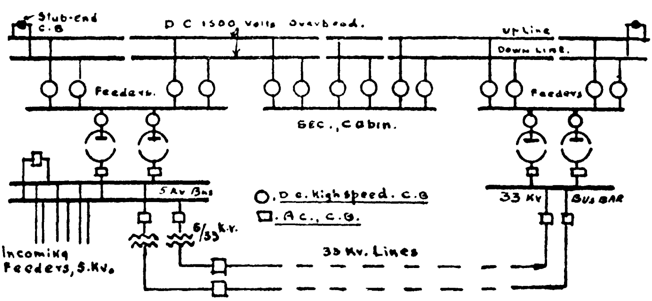


Fig. No. 18. S. I. Ry. 1500-V lines—feeding arrangements.

[Courtesy of '*Indian and Eastern Engineer*'.]

Power Station of the Madras Electric Supply Corporation. It is stepped down to 1,168 volts, 6-phase, by oil-cooled transformers. This is then changed into 1,500 volts D. C., by 2 steel-cylinder water-jacketed mercury arc rectifiers, for traction motors and locomotives. Each rectifier is designed for a maximum temperature of 60°C., and rated at 500 amperes, continuous, and can give 1,225 kW for 3 minutes and 750 kW continuously; the high speed D.C. circuit breaker being good for 1,500 amperes for 1 minute. The rectifier temperature is maintained under 60° C. Other transformers, 5000/400V, lower the incoming high voltage to A. C. 400/230 volts for lighting, etc. There is a motor-generator set for charging the batteries of the Battery Tenders when they come to Egmore. Each battery consists of about 200 cells. H. T. transformers at Egmore substation raise the voltage to 33 kV for transmission to the substation seven miles away at Minambak-

kam, whence a 5,000–volt 6–mile line runs to Tambaram where the electrified section terminates, and where also there are arrangements for reducing the pressure to 400/230 volts A. C. and for charging the batteries. The control room on the middle floor of the Egmore Receiving Station indicates by means of illuminated diagrams the condition of the circuits and lines at any time for the guidance of the operators or station attendants. At Tambaram, there exists a repair shop with a long and deep pit below rail-level, and there are flood-lighting projectors for work at night-time.

The overhead line consists of a copper catenary conductor 0.25 sq. in. sectional area with a copper contact-wire 0.2 sq. in. below it. The pantograph touching the contact-wire is first raised by a hand pump and kept up by vacuum on a coach and on a locomotive by an air-compressor, which is worked by a 3.88 h. p. motor. The motor-generator for lighting the trains consists of a 7.5 h. p. motor coupled to a 4 kW generator giving 60 volts. As the multiple-unit stock is of the articulated type, 4 turn-tables with hydraulic jacks have been provided at the car shed at Tambaram where 4 main motors can be overhauled and put in place of those taken out of one unit. Each traction motor in a coach is rated at 120 h. p., 750 volts, 560 r. p. m. and is fitted with roller bearings and ventilating fans, the temperature being kept below 90 degrees. Each motor is tested to stand cent per cent over-load for half an hour but in actual service carries about one-third of the maximum. The loco. motors are 160 h. p. each ; an extra speed position is obtainable by field tapping.

For purposes of signalling, daylight signals coloured red, yellow and green are in use. Each aspect can be seen in bright daylight for 2,000 feet. In case the main filament of the signal lamps gets burnt out, the auxiliary filament continues to give light. If the green aspect fails, the yellow is signalled and if the yellow colour is not seen, the red one is shown. If the red light goes out, the signal stays dark. The points, level crossing gates etc., are power-operated and inter-locked with the signals.

Commercial Aspect.

As regards the commercial aspect of electrification, we can not do better than quote from a letter dated 8–9–1939 from the Chief Commercial Superintendent, Trichinopoly :—

"After 5 years of intensive work, carried out under many difficulties due to the necessity of keeping the line open for traffic, the scheme providing a double electric line between Tambaram and Beach (Madras) and a single steam line adjoining to carry main line trains was finished and electric trains took up the service from

20th of April 1931. From that date, 29 trains in each direction were introduced as compared with 12 on the old steam line : the journey from Tambaram to Beach was reduced from 1 hour and 40 minutes to 42 minutes : and fast through trains for the residents of Conjeevaram (21 miles from Chingleput), hauled by steam engines beyond Tambaram (20 miles from Chingleput and 18 miles from Beach) and by electric locomotives on the suburban area, were introduced. Since that time great progress has been made : and to-day there are 78 trains running in each direction and the journey-time from Pallavaram to Beach is only 32½ minutes, see Fig. 21.

It is no longer necessary for the public to come to the station for a particular train, as during the morning hours there is a train running every 6 minutes and during the evening hours every 7 minutes. During the rest of the day, from 4.30 to 23.20 hours, trains are running at frequent intervals. 'The average consumption per day is about 14,500 units and the maximum demand on the half-hour basis about 1,500 kW.'

The public of Madras were not slow to realise the benefits to be derived from the Railway's enterprise, and modern houses and new townships have sprung up along the route. To-day such places as Mambalam and Kodambakam have become small cities in themselves planned on modern healthy lines far different from the old congested residential areas in Madras city. Statistics show that over 3,000 new houses, of which a great number are large upper-storied houses, have sprung up within the immediate vicinity of the railway line between Chetpat and Tambaram. The authorities of the Christian College realising that the health of their students was as much to be considered as their studies have shifted their college to the salubrious atmosphere of Tambaram, and in June 1937 opened their new palatial college buildings where they accommodate 450 student boarders and also cater for 300 day students. For the latter, a college special is run daily from Madras Beach, non-stopping after Saidapet, in the morning and returning again in the evening. (The poem at the end of this chapter is taken with thanks from the September 1939 number of the magazine of this college and slightly modified.—S. N.)

The growth of traffic has been startling in its rapidity. In 1927–1928, less than 3 million passengers were carried on the suburban area and in 1937–38 the figure has risen to over 9 millions of which practically one third were season ticket holders. Since 1932, over 50 million passengers have been carried with comfort, speed and safety, protected by the most modern devices known to railway signal engineers". The total single-track mileage electrified at present together with sidings comes to 46 miles.

If in the future traffic grows beyond Tambaram and if financial conditions improve after the War now going on, it is to be expected that electrification will be extended to Chingleput which is 38 miles from Beach or 35 from Egmore in Madras. The high voltage of 33,000 volts from Egmore to Minambakkam will then be justified, and history will repeat itself, for this is what has happened in Bombay where the B. B. & C. I. Ry. at first electrified up to Kandivli (19½ miles) and then extended electrification to Virar (37¾ miles from Bombay): though there the voltage used is 22,000 volts. On the G. I. P. Ry. the suburban service extends to nearly the same distance, as Kalyan is 34 miles from Victoria Terminus (Bombay). For a portion of the line to be electrified, the S. I. Ry. could use hydro-electric power from Mettur Dam where a water power plant is now working in co-operation with the older Pykara hydro-electric installation.

Mercury Arc Rectifiers.

With a view to avoid the use of rotating machinery, the S. I. Railway installed steel cylinder mercury-arc-rectifiers, at both the Egmore and the Minambakkam Substations, to change the nature of the current from alternating to direct; this railway being the first in India to instal large mercury rectifiers in steel tanks—the commoner glass-container variety having been used formerly in Bombay substations of the B. E. S. T. (see Fig. 31), and elsewhere. Subsequently, following the example of the S. I. Ry., the B. B. & C. I. Ry. installed large mercury rectifiers in their new traction substation at Bassein Road of 2,000 kW each, but the latter are of the glass-bulb type. In the original installations of both the B. B. & C. I. and G. I. P. railways, rotary converters had been put up for the purpose of rectification of the current. Like these converters, the rectifiers installed in the traction substations are meant for changing 6-phase a. c. supply to d. c. (the ratio between the voltages at the two sides being fixed),—the 6-phase current being better than 3-phase for conversion and being easily obtained from the ordinary oil-cooled 3-phase transformers (or, as is more often the case, from a bank of three single-phase transformers) by splitting the secondary sides (double-star, double-delta or diametral connection) while keeping the primary sides 3-phase (star or delta) for the 3-phase incoming supply. Each six-phase rectifier contains 12 main anodes, spaced 30 degrees apart in the cylinder, the mercury at the bottom forming the cathode. A tertiary winding in the main transformer supplies current to the ignition anodes. For striking the arc, the central ignition anode is momentarily dipped into the

mercury by a solenoid energised by current from a small metal rectifier. As in the thermionic valve, control grids are sometimes fixed to take care of variations in the d.c. voltage; these grids being connected to a potential distributor driven by a synchronous motor. To keep the vessel cool, annular water-coolers and finned air re-coolers with their sources of water and air, pump and centrifugal blower automatically worked when temperature changes, are provided. Mercury-vapour and rotary pumps keep the vacuum intact inside the tank; an electrical indicator showing the degree of vacuum in microns. Unevenness in the voltage-wave or ripple is smoothed down by a circuit consisting of resistors, reactors and condensers suitably made and connected for this purpose. (Recently pumpless rectifiers carrying currents upto 1000 amps. have been produced. For currents below 250 amps., the steel-tank type is not ordinarily employed) Contrary to customary procedure, in the S. I. R. substations, the neutral of the transformer is connected to the overhead contact wire and the cathode of the rectifier which forms the positive of the d. c. system is connected to the rails and thus kept at earth potential. The wear of the wire, due to arcing, is reduced and the necessity for insulating the cooling water pipe is obviated as the rectifier tank is not likely to be more than 30 V above earth potential.

The following extracts are reproduced with thanks from a letter kindly sent to me by the Electric Traction Engineer, Tambaram :—

"High-accuracy energy meters, incorporating electro-mechanical summation for total units and maximum demand, have been installed at the Egmore Substation for ascertaining the total energy supplied by the Madras Electric Supply Corporation to the Railway.

The particulars of the rectifiers are as follows :—

Brown Boveri Metal tank-No.-4. Input—a. c.; 1,168 volts, 50 cycles, 6-phases fed by 1,110 KVA star double-fork transformer: output—d. c.; 1,500 volts, 750 kW for each rectifier continuous (750 A for 2 hours, 850 A for 5 minutes, 1500 A for 1 minute and 2200 A momentarily). These rectifiers have given excellent service for the past 8 years, and apart from the comparatively low cost of installation and maintenance and the simplicity of operation, the high efficiency ensured over the whole working range is commendable. Suitable wave-filter equipments tuned for 300, 600, 900 and 1200 cycles have been installed to eliminate interference with the telephone and other communication circuits.

From Egmore to Beach a 5000-volt 3-phase 50-cycle cable is provided for the supply of light and power to stations and for automatic signalling. Between Egmore and Minambakkam a 5000-

volt line is also carried on the overhead contact-line structures in order to supply electricity for lighting etc. to the stations.

At Beach station, a 5000-volt switchgear has been installed through which an alternative supply can be obtained from the M. E. S. Co. at times of emergency for maintaining the signalling and lighting services independently of the main supply. Thus, over the whole section duplicate feeders are available to minimise delays due to faults etc.

At certain points, 'section switches' are inserted in the catenary and contact wires to enable any length of overhead conductor to be isolated whenever required. All section switches are manually operated and are mounted on the steel structures which carry the overhead equipment but are worked from ground level.

High-speed circuit-breakers are installed at the substations and at the ends of the lines at Beach and Tambaram—at the latter places to connect together the Up and Down tracks so that the full sectional area of copper may be utilised to minimise voltage drop. Automatic earthing equipments have also been provided at the substations to ensure that the track is immediately and efficiently earthed on the occurrence of any fault in the overhead line and the possibility of any potential rise in the rails is eliminated.

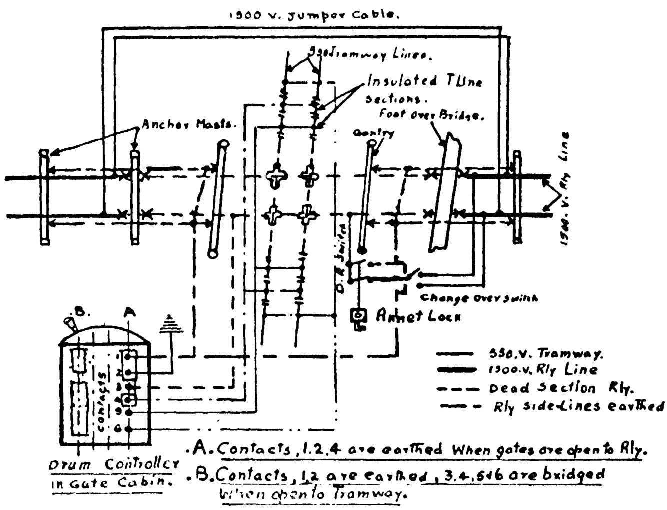


Fig. No. 19.

S. I. Ry. Railway-Tramway Electric Lines, crossing arrangements.

[Courtesy of '*Indian and Eastern Engineer*'.]

At cross-overs and other special track-work the rails are bonded by stranded copper conductors called jumpers. The steel-work of all track structures, pull-off masts, overbridges, etc. in the proximity of the overhead contact wire is earthed by connecting it to a continuous earth-cable running from Beach to Tambaram and earthed at every fifth mast approximately.

The double sliding doors in the passengers' compartments are fitted with hand-operated gear, so arranged that when one door is moved the other also moves in the opposite direction. The coach body is painted with superior aluminium, the interior being light apple green. The high-tension compartment contains all 1500–volt apparatus, including main isolating switch, solenoid-operated line breakers, motor-driven camshaft control equipment, reverser, motor-cut-out switches, main resistances, motor-generator-set, exhauster set, accelerating relay, etc. The door of this compartment and of the auxiliary compartment are interlocked so that they can not be opened until the main switches have been opened and the equipment earthed. A nickel-iron train-lighting battery is fitted under the coach for lights and fans, and also for operating the control equipment should the M.–G. set fail.

The driving compartment of the trailer coaches is fitted with a master controller, driver's brake valve controller, 'control switch set and trip', 'pantograph control switch' and switches for remote control of lights.

All the units are fitted with vacuum brakes. The pantographs on units are vacuum operated and are provided with a bow carrying hard-copper contact strips : and a special graphite lubricant is used to reduce the wear of the trolley wires.

Each unit can accommodate 176 third class and 32 second class passengers. The locomotives are for a combined passenger and goods service, and can haul goods trains upto a maximum of 600 tons, and are fitted with vacuum as well as air brakes.

Fig. No. 20. Electric Locomotive with Battery Tender, in shunting service at Egmore Yard, Madras.

[Curtesy of '*English Electric* Co.,

All the cleaning and washing and repairs are undertaken in the Car Shed at Tambaram, which is divided into 3 bays, one for inspection, another for overhaul and the third for painting. One interesting feature of it is that, unlike other repair shops, the whole ground level of the carshed is sunk 4½ feet, and the units are received in the inspection bay on rails erected on suitable supports and workmen work with the greatest amount of ease and speed. The overhaul bay is fitted with hydraulic lifting plant, consisting of 12 jacks which can be raised by oil pressure simultaneously in sets of 4 or 8 or 12 at a time, for one or two or three coaches as required. Turntables are provided under the bogies to enable the latter to be withdrawn to a separate platform, wherefrom they are lowered to the floor by the overhead crane, after the coaches have been lifted. All auxiliary equipments are provided with rollers and plug and socket connections, to enable work on them being done simultaneously with that on the bogies etc.

The Carshed is also equipped with a compressed-air plant for working pneumatic tools, cleaning, spray painting etc. Two lathes, and cutting, drilling and shaping machines, are also provided.

The rewinding of traction motor armatures has been undertaken very satisfactorily.

The suburban service started originally with a total of about 90 trains per day and to-day (Dec. 13, 1939) 160 trains are running per day : and the time taken for each trip is 42 minutes, stopping at all stations. Up to the end of March 1939, the electric multiple units have a total service mileage of 6,802,106 and the electric locomotives 575,438 and the number of passengers carried during the year 1938–39 was 8,186,931."

The following data are culled from Proceedings of the Institution of Civil Engineers, vol. 234, which contains a Paper dealing with the Electrification of the S. I. Railway :—

" Feeder cable from sub-station (a) Negative cable, one 0·5 sq. in. 1500–V,P.L.C.S.W.A. (b) Positive, 4 cables, 0·1 sq. in. with 'Anchahevi' insulation. Lightning Arrester, Dubilier condenser type. Earth Wire, continuous on structures, 0·0707 sq. in. Normal height of contact wire above rail level 17′ 3″ at 110°F. ; Maximum height 18′ at 60°F., 16′ 6½″ at 160°F. Displacement on straight track 9″, on curved track 1′ 3″, in mid-span 9″. Normal sag of catenary-5′ at 110°F. Spacing of supporting structures on tangent track–220′. Structure, expanded H–steel section ; two such forming gantry, on curves. Sectional area of bond per rail joint–0·15 sq. in. Total cost, **Rs. 78,34,102 *or* £ 587, 556." (Jan. 1934)**

The following notes are based on Mr. Krishnaswamy's article in " Indian and Eastern Engineer " for April 1938 :—

" In case of a fault, the faulty system is isolated and a duplicate system is immediately put into its place to keep things going as usual.

If the temperature rises beyond a safe limit for a rectifier the latter is disconnected automatically, an alarm and an indication being given simultaneously. It is also otherwise automatic in action. The rectifiers are kept cool by water circulated through cooling towers by pumps.

The Minambakkam substation is under the supervisory control of Egmore substation, to which it is similar except as regards the layout of the top floor which is entirely different. A continuous duplicate 33,000 V bus bar runs over a number of cells connected to either bus bar by vertical bare conductors, leads being taken below through insulators, thereby avoiding high tension cables and joints, which are costly to put up and to maintain.

The overhead current conduction is by means of a single catenary and a trolley wire suspended from the former (Fig. No. 21). These wires are carried over brackets, being kept up by insulators, on steel masts between the track, but at curves etc. lattice structures are used. The wires are anchored at every station, the ends being connected through air-break switches. The overhead conductors are fed at two points only near each substation ; half way between the substations there is a sectioning cabin. At each substation and at the Saidapet sectioning cabin, automatic high-speed circuit-breakers have been inserted in each feeder. If a fault is prolonged beyond a few seconds, the ci.cuit breaker trips and recloses thrice ; after this it stays ' out ', in case the fault persists.

There is an unusual cross-over in the city. The (1500 V) railway wires pass through copper strips with grooves in them, the (550 V) tramway wires being immediately below at right angles.* For 250 feet, the railway contact wires are isolated from the main line wires and the trains coast over this distance, The tramway wires are sectioned into small lengths on either side of this crossing and each portion is connected through leads to a control-drum in the adjoining gate cabin. The working of this overhead arrangement is interlocked with the position of the gate. (N. B. Fig. No. 19 shows how this is arranged. S.N.).

*In Bombay, tramways crossing the railways go on bridges over the latter or *vice versa* ; the G. I. P. Ry. has a high level station where one section of this railway goes over another section, see Chapter III.

Another overhead arrangement of an unusual character exists at Saidapet: the wires are raised 30 feet high to enable a Hindu Deity Temple car to pass by, which it would not do ordinarily on account of its extraordinary height. At the anchor mast, hand-operated winches raise and lower the wires; the driver of the train sees this 60 feet ahead of this point and lowers the pantograph in time.

Each unit of the rolling stock weighs 72 tons and accommodates upto 190 passengers. The traction motors are carried in two articulated bogies." The latest statistics kindly supplied by the Agent have been included in the last chapter in Table No. 10.

Fig. No. 21. Electric Train near Pallavaram, between Madras Beach and Tambaram. [Courtesy of '*English Electric Co.*'

The Electric Trains.

By storied house and acred farm,
By telegraph pole and leaning palm,
The trains rush on through storm and calm,
From Madras Beach to Tambaram—
Rattling in to Tambaram;
Rattling out of Tamabaram—
To the Beach from Tambaram.
While loud or low the winds blow on,
While red and green the lights glow on,
E'er back and forth the trains go on,
From Madras Beach to Tambaram—
Rattling in to Tambaram;
Rattling out of Tambaram—
To the Beach from Tambaram. (L. M. TURNER)

(N. B. For the photographs illustrating this chapter, I am indebted to the English Electric Co., Bombay; and for the diagrams to the "*Indian and Eastern Engineer*," Calcutta, who kindly lent the blocks. S. N.)

8

CHAPTER VII.

DIESEL-ELECTRIC RAILCARS AND LOCOMOTIVES.

Electric Railways, which rely upon power generated in distant power stations and transmitted through substations to their driving units, are able to compete with steam railways only in special circumstances as has been explained in previous chapters, though the advent of grid-controlled rectifiers or mutators with the possibility of using them with regenerative systems and the facility of reversibility of action does enlarge the field for further electrification of steam railways. Main-line electrification may still be out of the question if the traffic density is too low, but diesel-electric engines may offer a way out of the difficulty even in such cases because they score over steam locomotives in several respects.

Diesel vs. Steam Engines.

(1) The thermal efficiency of the diesel engine is about 40% compared with 15% for a steam engine of equal capacity. (2) The diesel locomotive uses cheaper fuel, generally speaking, thereby saving in cost per ton hauled. (N. B. For a train of 500 tons and a distance of 300 miles of waterless and coalless tract, the diesel loco. would require about 2 tons of oil whereas the steam engine would have to carry, if it could, about 10 tons of coal and 80 tons of water :—these quantities being however too heavy a burden for a loco., coaling and watering stations would be necessary and to these coal and water would have to be conveyed, thus still further increasing the expenditure). (3) In the diesel engine, cooling is effected in a closed vessel and rewatering is not required. (4) Only one man is required to drive a diesel loco., whereas at least two are needed for a steam engine. (5) Less time need be spent in cleaning a diesel engine, enabling it to cover a greater mileage per day. (6) Owing to the absence of cinders and the paucity of smoke with the diesel loco., it conduces to the greater comfort of passengers. (7) The diesel loco. can render quicker service for suburban traffic, shunting etc. on account of its ability to produce rapid acceleration. (8) It can run for a week, with brief intervals of rest, at a time, the driver having only to manipulate the switches etc., oil the bearings, examine the working parts and perform similar easy tasks as and when necessary. (9) The risk of fire is reduced to a large extent. (10) Even if costlier than a steam loco. to begin with, the diesel loco. may be cheaper in the long run owing to its lower cost of maintenance.

Two diesel electric locomotives are used by the B.B. & C.I. Ry., *see* page 43.

Diesel-Electric Railcars.

In diesel locomotives and railcars, besides the power plant being accommodated alongwith its auxiliary apparatus and equipment on the chassis, a portion of the space may be utilised for carrying seats for passengers and for luggage. The railcar is merely a variation of the loco., being smaller in size and power, and meant for light traffic and for shunting. "All the diesel-engine railcars at present in India have electrical transmission and no troubles have been experienced with the latter. The most important point of diesel maintenance is cleanliness. The ordinary steam running shed met with in India usually has an earth floor, with the result that dust is continually blowing about. For diesel units, a properly floored shed with doors should be provided. In India, the cheaper grades of fuel are not too well suited for use in high-speed engines unless passed through a centrifuge so as to pass the Government 'flame test'. The diesel engine having a very high 'availability ratio' will be out on the line for 18 to 20 hours a day." *Indian and Eastern Transport*, September 1939. The optimum serviceability ratio—Diesel to steam engine may be 1·6 and electric to steam 2·2.

Baroda State Railcars.

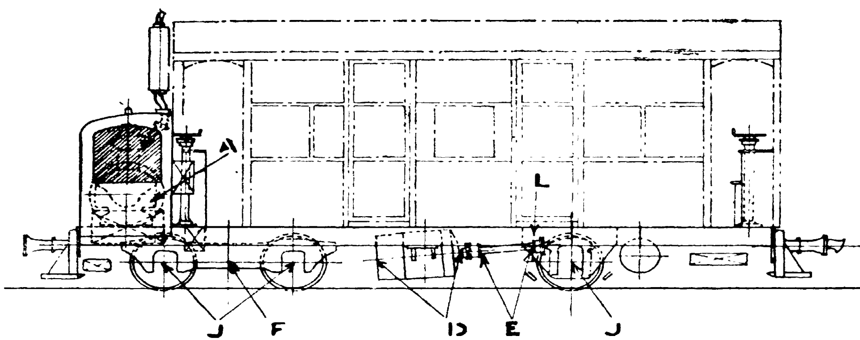
The Gaekwar Baroda State Railway authorities decided in 1932 to introduce diesel-electric railcars on about one-third of the total daily train mileage of the G. B. S. Railway. An official trial run was carried out on 22–12–32, after which a book was issued by R. B. Ram Kishan, Manager and Engineer-in-chief, from which book the information given herebelow has been culled. Four Armstrong-Saurer railcars were ordered in the first instance. The underframe of each railcar, which weighs 13 tons and is designed to haul a trailing load of 30 tons with 1% grade and 360′ curves at 20 miles per hour, is fitted with Diesel engine and electrical equipment. The engine has 6 cylinders ; its chassis corresponds to that of a 4–2–0 locomotive : and its ratings are 80 B. H. P. at 1600 r. p. m. continuous operation or 95 B. H. P. at 2000 r. p. m. for ½ hour operation. The fuel used during the trial was B. P. Co.'s 'Light Diesoleum', of specific gravity 0·843 at 60°F., flash-point 150° F., calorific value 19,600 B. Th. U./lb., and viscosity 35·4 seconds at 100°F. Redwood No. 1. The trial duration was made up of the following periods :— 2 hours at 80 H. P. 1600 r. p. m. ; ½ hour at 95 H. P. 2000 r. p. m. ; ½ hour at 60 H. P. 1600 r. p. m. ; ½ hour at 40 H. P., 1600 r. p. m. ; and

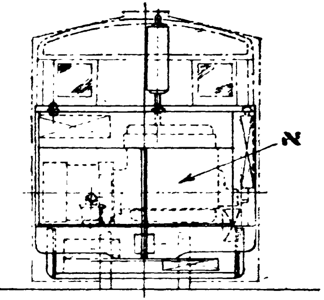
G. B. D. R.

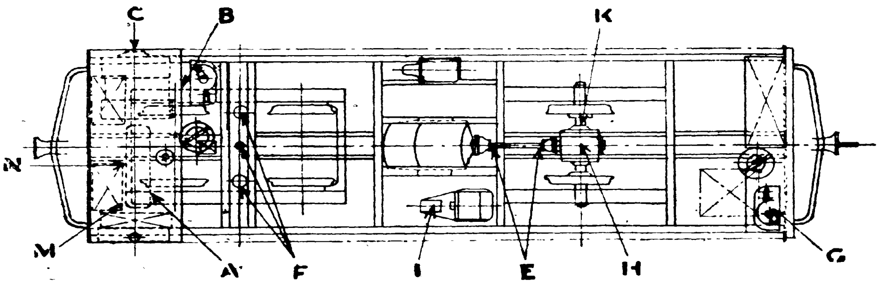
LUBRICATION CHART

FOR

LIGHT DIESEL ELECTRIC RAIL CAR.







	PART	LETTER	PERIOD	TYPE OF LUB.
	ENGINE SUMP	A	Z	
	ENGINE SUMP	A	X	
	CONTROL LINKS	B	Y	OIL
*	GENERATOR BRNG	C	W	CRIMSANGERE "BB"
*	MOTOR BRNGS	D	W	CRIMSANGERE "BB"
*	CARDEN SHAFT	E	U	WAKEFIELD UNIJOINT
*	BOGIE PIN AND SIDE BEARERS	F	Y	WAKEFIELD CASTROLEASE M
*	CONTROLLER SHAFT AND BEVELS ETC	G	U	WAKEFIELD CASTROLEASE M
	WORM GEAR	H	T	CASTROL R
	WORM GEAR	H	W	CASTROL R
	COMPRESSOR	I	TW	DTE HEAVY MEDIUM
	AXLE BOXES	J	S	SHELL C3
*	DRIVING AXLE GLANDS	K	Y	WAKEFIELD CASTROLEASE M
*	TORQUE ROD.	L	Y	WAKEFIELD CASTROLEASE M
	WATER PUMP	M	Z	YELLOW GREASE AND GRAPHITE
	FUEL PUMP	N	Y	ENGINE LUB OIL

Z = CHECK DAILY	X = CHANGE EVERY MONTH	U = GREASE EVERY MONTH	S = CHANGE AFTER 100,000 MILES
Y = WEEKLY	W = CHANGE EVERY 3 MONTHS	T = CHECK EVERY WEEK	* = TELCAMIT NIPPLE

½ hour idling at 400 r. p. m., approximately. The total distance was 158 miles involving grades of 0·5, 0·66 and 0·4 per cent.

The direct-current generator, direct-coupled to the engine, is rated at 500 volts and 120 amperes and is provided with interpoles or commutating poles and 3 windings self-excited, separatedly excited and extended series—the last of which is for use when the generator is worked as a motor for starting the engine, the starting current being supplied by a secondary or storage battery. The driving motor is a series-wound d. c. machine. The stationary portion of the generator (yoke and field-spools) is bolted in exactly the same position that a gear-box would normally occupy in an engine frame. One end of the armature is carried in a roller bearing and the other is bolted on to the end of the crank-shaft instead of to a flywheel. The ignition temperature of the fuel in heavy-oil engines ranges from 280°C. to 380°C. and compression pressure from 450 to 500 lbs. With this pressure, the air in the cylinder is heated to approximately 550 to 600°C. which is ample to ignite the fuel injected in the form of a very fine spray (no plugs, magneto or carburettor being required). The life of the diesel engine is estimated at about 20 years. It is cooled by means of a radiator, fan and water-pump and lubricated by oil forced by an oil-pump. The frame is all electrically welded. The crank-shaft consists of 7 separate sections bolted together. The special-alloy pistons are fitted with 4 compression and 2 scraper rings. The camshaft is situated in the crank case, having 5 bearings and runs immersed in oil. The cylinder head is detachable and carries the valves. There is an air compressor for working the brakes. Fig. No. 22, reproduced from a block entitled 'Lubrication Chart' kindly lent by Manager, G. B. S. R., shows all parts of the Railcar and states the type of lubrication for each part.

The driving motor is permanently coupled to the driving axle through a carden shaft and reversible worm. Between the generator and motor, there is a simple drum-type controller with reversing and power handles—the latter of which also automatically control the engine fuel pump. The generator is not only used for supplying current to the traction motor and train lights but also for charging the battery—it is itself driven by the current from the battery as a motor when starting the engine. The power plant can be easily inspected and taken out for repairs. It can occupy any place on the car, as it is connected with the controller by cables. A driving cabin with the necessary equipment is arranged at both ends of the car. There are no gears to change or clutch to operate. For the trial run, the trailing load was 33 tons and the average speed of

25 m. p. h. was maintained. The running cost worked out to 1·264 anna per train-mile. Experience in other countries shows that the cost is about half that of light steam locomotives.

G. I. P. (C. P. Ry.), Madras & Southern Mahratta and Bengal Railway Railcars.

A diesel-electric car is in use on the Pulgaon-Arvi branch of the C. P. Ry. worked by the G. I. P. Ry. A typical example of the Madras and Southern Mahratta Railway's diesel-electric cars which are being used in Godavari District is that supplied by Messrs. Armstrong Whitworth & Co. which also has a 6-cylinder Saurer engine-unit as used for the Baroda Government Railways but bigger in every way—160 H. P., 69 ft. long, with a tare weight of 27 tons. The bore of the engine is 5·1″, the stroke being 7·1″. There are 4 valves per cylinder, the inlet valves being shrouded. Central injection and dual turbulence are provided for. The direct-current generator is installed in a compartment situated behind the driving cabin. Only one traction motor is employed, this being suspended from the underframe beneath which is located the battery as also the switchgear. The power unit is so fitted as to be removable without difficulty. Westinghouse brakes and air sanding with electric control are provided for. A rail car having a Perkins engine and a Commer chassis which cost Rs. 10000 and makes 19 m. p. g. is in use on the Baraset-Basirhat Light Railway in Bengal. I. & E. Engineer, October 1938. (See Figs. 23, 24 & 25, kindly supplied by the '*Indian & Eastern Engineer*,' Calcutta).

Fig. 23. Bengal Diesel Railcar.
(Courtesy of *I. & E.Engineer*)

G. I. P. Ry., (C. P. Ry.) Diesel Electric Railcar.

The following information has been taken, with thanks, from a Note kindly supplied by the Secretary, G. I. P. Railway, Bombay:–

"The Pulgaon-Arvi section of the Central Provinces Railways is worked by the G. I. P. Ry. for the Managing Agents, Messrs,

Killick Nixon & Co. Ltd. The line, which is of 2′6″ gauge, is 22 miles long and has a maximum gradient of 1 in 80 for a distance of about ¾ mile. A main road runs almost parallel for its entire length. Both passenger and goods traffic were formerly operated in mixed trains and the running time was about 1 hour and 35 minutes in either direction, the maximum permissible speed being 30 m. p. h. In August 1932, the question of the serious decline in traffic and decrease in earnings due to intensive competition of motor vehicles plying on adjacent roads was taken up.

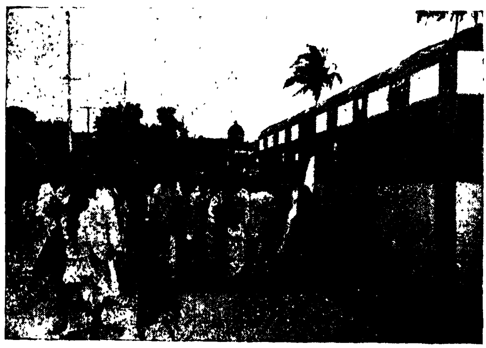


Fig. 24. Bengal Diesel Railcar.
(Courtesy of *I. & E. Engineer.*)

Exhaustive investigation led to the introduction of the Diesel Electric Railcar. The chassis of the vehicle with the power units (one of them spare) were imported from England and the body was manufactured in the G. I. P. Ry. workshops at Matunga.

The power unit is mounted on rollers to enable it to be replaced quickly. It is an Armstrong Saurer 6-cylinder engine directly coupled to a generator. The cylinders are of 130 mm. bore and 180 mm. stroke. The generator is provided with starter windings to avoid the need for a separate starting motor.

The traction motor, which is secured under the chassis, drives a single axle through a carden shaft and Craven Guest worm drive.

The engine will develop 122 b. h. p. at 1400 r. p. m. (continuous) and 140 b. h. p. at 1500 r. p. m. A motor-driven compressor provides air at pressure for working the brakes. All axles are fitted with totally-enclosed Isothermos axle boxes. A hand brake is fitted as well as a 'deadman's device' to cut off power and apply the brakes in emergency. Draw gear of the central coupler type is fitted to each end of the vehicle so that a trailer can be hauled.

The underframe is 45′ long and 6′5″ wide, the maximum dimension in length being 48′8½″ over buffers and in width 7′6″ over head-

stocks. The diameters of the wheels on tread are 1'11", there being 4 pairs of wheels, the bogie wheel base being 4'6" and the bogie centres being 31'6" apart.

The body is built of teak wood pillars and framing with a 3/16" plywood finish inside and out. The inside dimensions are 44'8" length, 7'2" width and 7' $3\frac{5}{16}$" height from floor to roof at the centre. The outside diamensions are 45' length, 7'6" width and 10'6" maximum height above rail level. The total seating accommodation is for 58 passengers. There are 4 compartments, 3 for the driver, guard and luggage and engine, and one for the passengers.

The oil fuel consumption averages 17·7 gallons per 100 railcar miles. Four ground tanks for storing oil and a hand pump for lifting the oil to a high service tank are provided at Pulgaon.

A trailer providing only 3rd class accommodation is attached, according to the needs of traffic, on bazaar and other days. This trailer can seat 48 passengers and has a lavatory and a guard's brake with room for luggage and parcels. All upper class accommodation has been abolished on this branch line.

At present the Railcar does 2 round trips daily—completing the journey in one direction in periods varying from 56 minutes to 1 hour and 11 minutes, depending upon the number of halts. There are 2 mixed trains also in each direction daily, completing the journey in one direction in about 1 hour and 16 minutes. The maximum permissible speed on the straight is 40 m. p. h. for the Diesel Car and 30 m. p. h. for the steam locomotive trains. Four additional halt stations have been provided along this branch.

It is the practice to change power units after every 20,000 miles in service. Periodical overhauls are given in the Parel and Matunga workshops about once in 2 years; the period extending to about 2 months; at such times, the service between Pulgaon and Arvi is operated entirely by steam.

The introduction of this accelerated Diesel-unit service and the reduction in the basis of charge for passengers have succeeded in restoring to the Railway the traffic previously lost to the roads."

Diesel-Electric Railcars in England.

The following particulars apply to a typical Diesel-electric railcar for use on a broad gauge track:-length 60 feet; seats for passengers 60, besides those in the luggage van when empty; weight 45 tons; engine-power 250-H. P.; maximum speed 65 miles per hour; control from both ends, avoiding use of a turn-table. Such a railcar is in use on the L. N. E. Railway in England, where on a 6% grade it beat the steam train timing by 7 minutes in 45 and quickly accelerated to

65 m. p. h. on the main line. The G. W. R. has a number of railcars. The L. M. S. R. is experimenting with a triple-articulated unit having six 125 h. p. engines for service between Oxford and Cambridge.

Diesel Traction in other Countries.

A 5-coach train having a 1200-H. P. mobile power house was put into service in 1929 and another in 1930 by the Buenos Aires Great Southern Railway of Argentina, South America. These trains are equipped for working in multiple, thus giving 2400 horse power for moving 1088 passengers. Three additional 1700-H. P. sets were ordered later, each consisting of two 850-H. P. diesel-electric units, weighing 103 tons i. e. 135 lbs. per B. H. P. Diesel-electric coaches, 200 H. P., are in use on the Venezuela Central Ry. Russia had in 1932 half a dozen Diesel-electric locomotives and six dozen on order. England, Sweden, Switzerland, Italy, Austria, Holland and other countries of the West have several such units in operation. The Canadian National Railways have, besides a number of rail-coaches, diesel locomotives of 2,360—3,000 B. H. P. for a section of their line. Diesel-electric locomotives are also in use in Brazil, Denmark, Siam or Thai, Manchuria, Africa, Ceylon, U. S. A., Chile, Argentine, Japan, Egypt, etc. In Germany, the diesel-electric 150-ton train (Hamburg Flyer) attained the *record* speed of 127·3 miles per hour between Hamburg and Berlin as against 78 m. p. h. of the 'Flying Hamburger'. It is fitted with two 12-cylinder 600-h. p. engines and a 15-kW motor for starting. The diesel-electric train is for 109 3rd class and 30 2nd class passengers and is made up of 3 articulated stream-lined cars, whereas the 'Flying Hamburger' is for 100 passengers and is articulated from 2 cars.

American Diesel Electric Locomotives

A new stream-lined train operates now between New York and Florida and earns a profit of 4 dollars per mile on each trip. From New York to Washington, an electric locomotive brings the train in the way described in the next chapter. From Washington, two 12-cylinder 1000-h.p. 2-stroke V-type Diesel engines, making a 2000 h.p. combination, move the train to Florida. Each engine has a 600 V d. c. generator coupled to it. There are 4 axles of two 6-wheel bogies. The train has 280 revenue-producing seats. Behind the loco., there are attached 7 coaches, each about 85′ long.

The following statistics from the G. E. Review for March 1932 give comparative hourly operating costs in dollars of steam and diesel-electric American locomotives for the years 1928 and 1930 :—

Table No. 4. Diesel-electric vs. Steam Locomotives.

	(Industrial Service, 1928.)		(Switching Service, 1930.)	
	Diesel-electric.	Steam.	Diesel-electric.	Steam.
Fuel ..	\$0·231	1·308	0·404	1·453
Lubrication ..	0·058	0·039	0·051	0·014
Maintenance .	0·367	1·253	0·501	2·610
Crew ..	0·894	1·712	1·642	1·650
Water ..	...	0·013		
Other expenses ...			0·003	0·190
Cost per hour ...	1·550	4·325	2·601	5·917
Saving over steam loco.		2 775		3·316

Special Diesel–Electric Vehicles.

The metre–gauge Nilgiri Ry. from Mettupalaiyam to Ootacamund in the province of Madras has a rack and pinion arrangement to enable the steam locos. to propel the train up a steep incline on the top section of the railway near Coonoor. Diesel–electric locomotives might be found useful here. In this connection, the following extract from "Electrical Engineering" for October 1939 will be read with interest :—

"A rack–rail Diesel–Electric locomotive, said to be the first of its kind, has been built by the General Electric Company for the Manitou and Pike's Peak Railway, replacing the tilted steam locomotives used on the cog railway since its completion in 1891. Instead of hauling its load, the locomotive pushes a 50–passenger car from Manitou, Colo, at 6,562 ft. elevation, to the top of Pike's Peak, 14,109 ft. above sea level. The average grade is 16% and the steepest 25%. The new loco. can provide traction at the wheels as well as the rack–rail, but not simultaneously. It has 2 axles, weighs 20 tons, and is powered by 3 generating units, each rated 160 h. p. at elevation of 1,800 ft. One control station is provided, and the same standard electric–drive equipment as is used in the company's new Diesel–electric industrial locomotives".

Another diesel-electric vehicle which is unique is the one called 'Snow Cruiser' and employed by the American Antartic Expedition. It weighs 35 tons, carries an aeroplane, cost £30,000, has 2 diesel-electric 150 horse-power plants and 4 motors on each wheel. (*Electrician*, 28/7/39). It can cover 5000 miles. Flameproof diesel locomotives, for use in gassy mines and dangerous areas such as the vicinity of inflammable and explosive material, have been described in the Oct. 1939 number of 'Overseas Engineer'.

Non-Electric Diesel Railcars, in India.

Railcars run by diesel engines, with mechanical transmission, are in use on the following railways in India, among others:—Kalka Simla, Nizam's State, Jodhpur (State), North Western, i. e. N. W. R., Bikaner State. Eleven diesel railcars, each having 8 wheels and weighing 44½ tons, have been in service on the N. W. R. on certain branch lines near Jullundur since May 15, 1939. They have been supplied by Messrs. Ganz & Co,, a Budapest firm, and are the first of their kind in India. The total cost of the consignment was about 14 lakhs of rupees. The engine is of 250 H. P. 1300 r. p. m., and is provided with a clutch and a 5-speed gear-box—there is a water tank for ample water supply. The car attains a speed (max.) of 60 m. p. h. and can carry 101 passengers There is no smoke nuisance, no dust-cloud, no thundering past bridges and wayside stations. The travelling is therefore done in safety and comfort. The electrical machinery consists of a 2-kW generator to charge the 24-V 400-Ah battery for lighting and for controls which are operated electro-pneumatically. There are no electrically driven trains on the N. W. R. system. The contract for 2 Diesel-electric 1300 H. P. locomotives was cancelled. An article by Mr. G. K. Ambady of the N. W. R. in Vol. 137 for 1937 of *Proc. I. Mech. E.* deals in detail with Diesel Traction on Railways: "The wear and tear caused by a diesel-electric loco. is less than with a steam unit, due to lighter action on the track ".

Figs. 23, 24, and 25 show a Bengal Railway Diesel Railcar and its engine ; for further information, please turn to page 62. The S. I. Ry. may introduce diesel locos. for their services, beyond the electrified section, to Conjeevaram, see page 50.

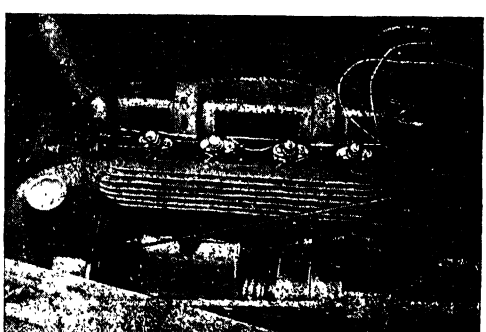


Fig. 25. Perkins Engine, interior.

(Courtesy, *I. & E. Engineer.*)

CHAPTER VIII.

SINGLE-PHASE ELECTRIC RAILWAY PROJECTS.

Over 30 years ago, at about the same time as the hydro-electric installation on the Jhelum River at Mohora, Kashmir State, between Murree and Srinagar (illustrated descriptions of which may be seen in Chapter III of '*Hydro-electric Installations of India*' and in Chapter V of '*Indian Water Power Plants*') was projected, it had been proposed to transmit a part of the electric power that would be generated by the harnessing of the river to substations to be located along a railway from Abbottabad (North-West Frontier Province) to Srinagar (Kashmir State)—a distance of 156 miles—to be covered in 9 hours on a single track during hours of daylight and twilight only. Though this railway did not materialise, a brief description of the project will nevertheless be not without interest as it was not only the first scheme of railway electrification for any part of India for which specifications were called for and prepared but one which would have employed a system not hitherto in vogue on any of the Indian railways—a system which may however be employed elsewhere in India, e. g. in Mysore State where the generating plant and equipment for transmission and distribution were obtained from the same American firm—the General Electric Co. of Schenectady—that put up the plant and equipment required for the Jhelum Power Installation and prepared the specifications for the Kashmir Electric Railway from which the information given herebelow has been culled. In passing, it may be mentioned that illustrated accounts of the Mysore State schemes may be seen in Chapter IV of '*Hydro-Electric Installations of India*' and in Chapter IV of '*Indian Water Power Plants.*'

In Kashmir as in Mysore, three-phase generators, rated at 2300 volts and 25 cycles per second, have been installed ; and the transmission voltage was fixed at 30,000 volts, in the first instance. The Mysore State Installation at Sivasamudram has gone on from strength to strength and the transmission voltage has been raised to 78,000 volts, whereas the Kashmir State Installation has stayed put at its original capacity and the ideas of industrial development and electric railway long ago evaporated into the thin air of dreams. Between Mysore and Bangalore, there exists a fairly frequent train service which may justify railway electrification if the State continues to progress in the future as it has been doing uptil now. If and when electric traction is re-

solved upon by the Mysore Government, the single-phase system is likely to be adopted, as has happened in similar circumstances in Europe and the United States of America.

Advantages of Single-phase System.

(1) The existing plant generates and transmits electric power alternating at 25 cycles or periods per second, which is a suitable frequency for electric traction. (2) Three-phase power can be efficiently converted into single-phase power (of a lower frequency, if desired) by means of grid-controlled mercury-vapour rectifiers or *mutators*, see Appendix. (3) High voltages, up to 15,000 volts, can be safely employed for overhead conduction, thereby effecting a considerable saving in cost. (4) The efficiency of the system compares favourably with that of other systems of electrification. The lower the frequency, the lesser the cost of power station and substation apparatus, the size and weight of motors etc. being smaller. The use of high voltage for traction lines either eliminates or reduces losses due to step-up and step-down transformers at stations and substations, but interference is caused by overhead lines with telephone, telegraph and broadcasting circuits which must therefore be put on structures away from railway lines. The following Table (believed to be from a competent and reliable source, L. Thorman, *vide Electrotechnics*, April 1935) gives efficiencies of different systems of electric traction.

TABLE No. 5

(Average Efficiencies, of different Systems)

(Generator shaft to Wheel Rim of Locomotive)

	3000 V D. C.	15,000 V Single-phase	
		from 3-ph. supply	direct.
1. Locomotives ...	0·8	0·76	0·76
2. Overhead Conductors ...	0·9	0·92	0·92
3. Motor Generator Set ...	0·78	0·80	...
4. Double Transformation ...	0·90	0·91	0·91
5. Transmission ...	0·94	0·94	0·94
Overall Efficiency ...	0·475	0·48	0·60

It will be seen from this Table that the single-phase 15,000 V-direct system gives an overall efficiency of 60 p. c. compared with 48 p. c. obtained with the other systems: the latter may however attain higher efficiency than 48% if instead of motor-generator sets

synchronous converters, rectifiers or mutators were employed—a single-machine appliance for converting from 3-phase supply to d. c. or single-phase a. c. would naturally possess greater efficiency (other things being equal) than a 2-machine set consisting of a motor and a generator. Supposing the motor and generator had an efficiency separately of 0·9 each, the overall efficiency of the set would be 0·81. Assuming that the single-machine converter had an efficiency of 0·9, the overall efficiency of the systems which had an efficiency of 48% would improve to $48 \times 9/8$ or 54%, i. e. it would still be lower than that of the single-phase direct system. In order to attain an efficiency of 60%, the efficiency of the converter would have to be $60 \times 0{\cdot}8/48$ or 1 or 100% which is of course unrealisable in practice. The low-frequency single-phase system, in which high voltage is put on the overhead line, must therefore continue to score over other systems except under special circumstances. The low frequency system possesses the additional advantage that with it the charging current of the line is considerably less than with the 50 or 60 cycle system.

System Proposed for Kashmir Railway.

The power required for the railway was proposed to be taken from the line in 3 sections, two between Mohora and Abbottabad and one between Mohora and Srinagar, about 50 miles apart. The sectionalising stations at the two dividing points were to have 400kW transformers, whereas the other seven substations to have each 200 kW transformers, for stepping down from 30 or 60 kV to the railway overhead-line pressure of 3·3 kV—the substations to be located approximately 18 miles apart and to be attended only by train despatchers or section-men not by a separate set of attendants. The line voltage of 3·3 kV was to be reduced to 800V by means of a 'compensator' or autotransformer before being applied to the railway motor—no moving apparatus being interposed between the generating station and the electric cars or locomotives. The catenary was to be 3/8-in. single 7-strand steel cable from which was to be suspended the trolley wire—a grooved No. 000 B. & S.-gauge copper wire. The return circuit was, as usual, to be provided by the 30′ rails which were to be bonded at each joint by a 4/0 9-in. ribbon bond with compressed terminals and also bonded every 800 or 1000 feet. Tbe catenary and trolley wires were to be carried on straight line and anchorage brackets fixed on 30′ poles, 7-in. in diameter at the top and 11-in. at the bottom, buried 7 feet in the ground,—the wires to be suspended from good insulators meant for high voltages.

Rolling stock.

The rolling stock was to be for a metre-gauge single-track railway. The traffic which was expected to be moved consisted of 250 passengers and 250 tons of goods each way per day. For passenger traffic, each train was to comprise 3 cars, 2 of them motor-cars 35 tons each and the 3rd. a trailer of 20 tons, making the total weight 90 tons. Each motor-car was to be equipped with four 65–HP single-phase motors of the commutator type designed to give lowest speed on the grades and the highest on level portions, the motors being furnished with the Sprague multiple-unit potential control. Each train could ascend a 5 p. c. grade at 14 miles per hour and attain 24 m. p. h. along level country. For goods or freight traffic, the presence of a 7 p. c. grade and of extended 5 p. c. grades made it incumbent to employ locomotives. Four 75–HP motors to each loco. were to be provided, with control so arranged that 2 locos. could be operated as a single unit with the motorman or driver in the locomotive at the forward end of the train. Each loco. was to have 8 axles and to weigh 32 tons, the weight being entirely on the driving wheels. The tractive effort would be 14,000 lbs., enabling a 90–ton train to be hauled (but not started) up a 5% grade. A double train—two 32–ton locos. and two 90–ton trailing loads—cound attain a speed of 7.5 m. p. h. on the 5 p. c. grade. Each rail was to weigh 56 lbs. to the yard. The 24–hour energy consumption for both passenger and goods services was estimated at 12,000 kWh at the generating station.

An actual or working Single phase Railway.

Before bringing this chapter to a close, it seems desirable to give some facts and figures about a single-phase railroad which has been in actual working order for a number of years. Some statistics pertaining to the Pennsylvania Railroad have already been quoted in the first chapter of this book. Further information will be found below. A high-tension single-phase line delivers power through suitable step-down transformers to a nominal—12,000 V—single phase contact line. The high-tension side of the transformer is for 25–cycle 132,000 volts, except in 2 places where the pressure is 44 kV. There are 56 substations, made up (according to the *G. E. Review* of February 1936) of the following :—

6 for supplying power to the high-voltage distribution system ;
1 „ „ „ direct at 12 kV ;
40 for stepping down to 12 kV, spaced about 8 miles apart :
8 switching stations on the 12 kV system, and
1 synchronous-condenser station, for improving the power factor.

Some of the substations are under supervisory control by power directors. The overhead contact line consists of the catenary with contact conductor, the catenary having main and auxiliary messenger wires of bronze or copper, supported by three 5¾-in. disk type insulators. Besides these, there are flexible cross catenary wires suspended between steel poles on either side of the roadbed, each being a 19-strand high-strength bronze cable. The main messenger is a 5/8-in. cable of the same kind, having 13 p. c. conductivity of equivalent copper cable; the auxiliary messenger, a 4/0 grooved solid copper wire, with bronze-rod droppers spaced about 30 feet apart; the contact wire being a 4/0 grooved solid bronze conductor, having 40 p. c. copper-equivalent conductivity, supported by clips spaced about 15 feet apart. The signal transmission is by 6600-volt 100-cycle 1/0 copper conductors, 7 feet apart.

Single-phase high-tension Locomotives.

From the March 1936 number of the *G. E. Review*, it appears that the Pennsylvania Locomotives of different kinds possess the properties mentioned against each :—

Stream-lined Passenger--weight 460,000 lbs. (300,000 lbs. on the driving wheels), length 79′ 6″, wheel diameter 57″, speed 63 to 90 m. p. h., power 4,620 H. P., tractive effort 75,000 lbs. An oil-fired boiler is provided for 4,500 lbs. of water per hour ; the pressure being 200 lbs. (ii) Goods Locos. (formerly used for passenger traffic) weight 394,000 lbs. (229,000 lbs. on 3 drivers), length 62′8″, wheel diameter 72″, speed 56 to 90 m. p. h., power 3,750 H. P., tractive effort 57,250 lbs. The main transformer is for 11,000 V primary, 960 V secondary, 25 cycles per sec. The traction motor develops 1250 H. P.-Gear Ratio is 91/131. The motor has a twin-armature ; each armature being for 625 H. P. (iii) Freight loco.—weight 300,000 lbs. (150,000 lbs. on the wheels), length 52′8″, power 2,500 H. P., gear ratio 57/22. (Another type weighs 258 tons, develops 4800 H. P., 88,000 lbs. effort at 20.5 m. p. h. (4 motors); see Standard Handbook for Electrical Engineers, for further details).

One of the largest—if not the largest—electric locomotives in the world is the 12,000 H. P. loco. which is mainly used on the Gothard Line in Switzerland. It is in 2 units which are normally coupled together. To drive it, 16 traction motors with double reduction gears (ratio 3.47/1) are used. The electric supply is single-phase 15,000 V, 16⅔ cycles per second. The load on the driving wheels is 44,000 lbs. each. The total weight is 260,000 kgr. or 256 tons and the length (overall) is 111 feet, of which the wheel-base accounts for 95′8″. The diameter of the driving wheel is 1350 mm. In Germany, one of the locomotives on the Berlin-Munich service is rated at 5,800 kW and attains a speed of 112 m. p. h. (maximum, 140 m. p. h.). It is built as a single unit. In England, the London, Brighton, and South Coast Ry'. s monophase system uses compensated repulsion motors rated at 750 V, 25 cycle, 115 h. p. (1 hr. rating). The line P. D. is 6000 V. The stator winding is tapped at 3 points for variation of voltage applied to the motor. (*Maccall's* A. C. Electrical Engineering.)

CHAPTER IX

ELECTRIC STREET RAILWAYS.

This book deals primarily with electric railways and, strictly speaking, electric vehicles which run in the streets of cities e g. tramways are not usually classed as electric railways, but tramways are called street railways in some countries and a brief mention of them and of allied forms of electric vehicles will be given in this chapter. As regards tramways, it must be said that they represent a passing phase of street locomotion and few, if any, extensions of existing tram tracks are contemplated even in large cities. Starting with horse-drawn tramcars so called because Mr. *Ou–' tram'* invented them *or* because when first introduced they ran on 'trams' (another name for 'wooden beams'), the motive power has been changed from that of animals to that of machines driven by one of the three main motive powers of the civilised world of to-day, viz., steam, oil (including petrol) and electricity. Statistics regarding these sources of power in different countries of the world may be seen in "*Hydro-electric Stations in India.*" For traction inside city limits, electricity has superseded all other forms of power except in one or two cities. The track has also changed from that of wooden beams to one of iron rails or plates. The rails are either laid on the surface of city-roads or over or under the streets and structures. Street railways may, therefore, include A–Tramways and B (i) Over-head, B (ii) Under-ground, Railways.

A. Electric Tramways *or* Trolley Cars.

For the power required to move them, electric tramways rely upon current supplied by power stations *viz.* substations to overhead trolley wires whence it is conducted to electric motors under the tramcars to be returned to the source of supply through the rails which form the return circuit. The supply pressure is usually 550 to 600 volts direct current: alternating current is not used for trolley cars or buses. The cars can only run one behind the other, not parallel to each other, being confined to a pair of rails fixed in the ground. The route mileage is small compared to that of railways which transport passengers from city to city over long distances. For Indian cities, it is no where more than 38 route miles, which is approximately the double-track mileage for Calcutta, where over 106½ million passengers were carried in 1938 by about 315 cars. In Bombay, the route mileage is 31 miles: the total number of tramcars is 277. Madras comes next, with about half the figures for Bombay and then Delhi with ⅓ as much again for mileage and ¼ as much for number of cars. The Electric Supply and Tramways Company runs not only electric

tram-cars but also oil buses throughout Bombay: 100 million passengers were transported by them during 1938. In Karachi, the tramcars run on rails but are propelled by oil or petrol. Petrol cars are in use over sections of the Bikaner State Railway and some other railways. The Delhi Electric Supply and Traction Company runs tramcars as well as trolley buses, the latter obviating the necessity of laying rails on the roads. The tramways proposed to be run between Dehra Dun and Mussoorie and between Satara City and Satara Road Ry. Stn. of M. & S. M. Ry. have not materialised. Cawnpore scrapped its tramway system in 1933. During the War, tramways were restored in some English cities, in order to save petrol which buses would have consumed and which was urgently required for use in military machines. England has probably about 5,000 tramway miles of single track.

Certain facts and figures about tramways in India's principal capital cities, kindly supplied by the officers in charge of them, are qouted below or incorporated in Table No. 6. In Madras, at a place where the tramway lines cross those of the electric railway on the same level, an unusual cross-over has been provided as described in Chapter VI.

Madras Electric Tramways (28/11/39).

"The Madras Electric Tramways Co. Ltd., was incorporated in 1892, and the tramways were constructed under an order by the Madras Government dated 6/4/1892; the construction of the first track being commenced in 1894 and the *first* tramway section opened for use in May 1895. This tramway company was the *first* to run electric tramcars in the East, and is even older than many of the tramway companies in England.

This company was re-constructed, and the scope of its activities extended, in 1904. The tramways serve 16¼ miles of roads in the city of Madras and maintain a regular service over all routes.

The rolling stock comprises 103 single-deck cars, each equipped with two electric motors. The larger cars are equipped with electric and compressed air brakes in addition to hand brakes. The daily car mileage amounts to approximately 8840, and the number of passengers carried daily is approximately 75,530 ".

Calcutta Tramways (24/11/39).

"Gauge—4′8½″.

Rail—weight, 105. 7 and 110 lbs. per yd., B. S. S. 7 and 7c.

Rail—length of section, 45 ft.

Equipment—550 V, d. c. English Electric.

Motors—Dick Kerr, 25,29A, 29H and 133A.
Vehicles—315, in service daily. (In Howrah, 30)
Passengers carried in 1938—106,548,180.
Establishment—6000 (operatives, skilled labour and other staff)"
Fig. No. 26 shows a Calcutta thoroughfare with a tramcar on it.

Fig. No. 26. Tramcar in a Calcutta thoroughfare.
(Courtesy of English Electric Co.)

Bombay Tramways (21/11/39).

The B. E. S. & T. Co. was the first (Western India) electric lighting company to take out a license in 1905 under the name of the Brush Electric Engineering Co., Ltd.

"On the 1st. of Jan., 1915, the tramway system in Bombay was substantially the same as at present; but minor extensions have been made as follows, increasing the route mileage by 8·439 miles to a total of 30·877 miles :—

Section	*Date of Opening*
Parel Terminus to Dadar	June 1917
Girgaum to Opera House	Jan. 1919
Esplanade Road	Dec. 1919

Section	*Date of Opening*
Sandhurst Road	Apr. 1920
Reay Road	Apr. 1921
Tank Bunder	Oct. 1923
Grant Rd. terminus to Gowalia Tank	Feb. 1926
Mohammed Ali Road	Mar. 1931
Dadar to King's Circle	June 1935.

All the tramcars at the beginning of this period were of the single-deck type but the double-deck car was introduced in 1920 with a view to reducing traffic congestion. From 4 of this type put into operation in 1920, the number has since been increased to 89 with a corresponding reduction in the total number of units in operation, particularly of coupled units.

The electrification of the old horse tramway was commenced in 1905 and completed in 1908. The year 1915 was the 11th. year of operation of the electric tramway system and during those 11 years there had been a steady, though not spectacular, annual increase in the number of passengers carried and in car mileage (see Table No. 6). This increase was greatly accelerated from 1905 onwards to the peak year 1923, the number of passengers carried increasing from 41,154,599 with a car-mileage of 3,756,218 to 101,995,572 with a car mileage of 6,056,734. Both the number of passengers and car mileage dropped thereafter and reached the lowest figures in 1932. There has been a substantial recovery during recent years, the 1938 figures being 100,269,085 passengers and 5,921,974 car-miles, and this recovery is attributed to the extension of building activities towards the north of the Island, with consequent increased demand for transportation.

During the 25-year period (1915 to date), considerable advances have taken place in the design of cars. At the beginning of the period, the majority of the cars which were all single-deck were of the single truck type running as single units or coupled together to form trains. By the end of 1939, the numbers of each of the units are expected to be as follows:—

Single deck bogies, running as single units	29
Double " "	89
Single truck trains	144
Other cars and wagons for shunting, water, sand, cleaning, etc.	115

The latest model car is the centre-entrance double-deck bogie: of this type, 23 are now in service. The design follows the latest practice, but does not appear to meet with universal approval in Bombay owing to the jostling which takes place between alighting and embarking passengers. In previous designs, separate entrances and exits are provided, and some members of the travelling public have not yet become accustomed to the change.

The methods of service braking have been improved from hand ratchet type, through hand-ratchet geared type, to air-operated brakes, and the improvements in braking have permitted an increase in maximum speeds, outside the congested bazar areas, from 12 to 18 miles per hour. The percentage increase in average speeds has, however, been small owing to the large number of stopping stations on the system, which average 8 per mile.

Bombay Tramways (2-12-39) and (4-12-39).

"The B. E. S. and T. Co. maintains a regular tramcar service right through the city of Bombay from 4 o'clock in the morning to 0·30 in the

morning of the next day. The service covers 30,877 route miles which extend from Sassoon Dock in the south of the Island to King's Circle in the north and from Gowalia Tank in the west to Tank Bunder in the east.

In 1938 the total power consumed amounted to 12½ million kWh. The power is generated in the hydro-electric plants of the Tata group and is supplied to the B. E. S. T. in bulk at 5,500 and 6,600 volts, 3 phase, 50 cycles per second (see other instances of relation between hydro-electrics and traction in Appendix V).

Sub-stations.

Three substations, Esplanade, Lal Baug, and Kingsway, receive the power at high voltage either from the Receiving Station at Kussara or direct from Tata's, step it down and convert it to 600 volts d. c., which is fed into the traction line.

i. **Esplanade** Substation is a rotary converter station which feeds both the lighting and traction systems. The majority of the machines installed can be made to supply direct current either at 460 volts for lighting or 600 volts for traction, by changing the transformer tapping, which adjusts the alternating pressure on the incoming side of the converters. When supplying the traction load, the converters are given a compound characteristic by the insertion of a series field which is otherwise short-circuited by means of a double-throw switch; the second position of the switch connects the series field to an equaliser bar.

The bus bar distributes the current to the various feeders through overload circuit breakers and knife switches. On tripping, the circuit breakers are arranged to ring an alarm to warn the attendant, and are reset manually. A broken trolley wire in contact with the earth is indicated by repeated and strong blowouts.

ii. **Lal Baug** Substation is a new rectifier station of 500 kW capacity recently installed to supply the load that has been steadily increasing. It is started automatically every morning by a time switch at 6 o'clock and switches out at 10-30 at night. Two feeders run out from this station through a high-speed auto-reclose circuit breaker which springs into position 3 times after a short interval after each blow-out, before it finally locks out. The blowouts have to be concurrent for the lockout to function.

iii. **Kingsway** Substation has a rectifier set of 500 kW, a motor generator set of 500 kW and two 250 kW rotary converters. The rectifier is automatically operated by means of a time switch at 4-30 in the morning and cuts out at 11-00 at night. The other machines which are manually operated are put on load only during the heavy traffic period in the evening. An auto-reclose circuit breaker takes care of transient overloads. The characteristics of the motor-generator and rotary-converters have been altered where necessary to enable them to run in parallel with the rectifier.

The stations do not normally run in parallel for any length of time. According to routine procedure they are isolated shortly after they are switched on by removing cable loops fixed across section insulators on the overhead system.

Cable connections link up the four rails of the track, at convenient points close to the substations, with the negative bus.

Auxiliary Equipment.

Besides the power equipment, 4 negative boosters of a total capacity of 162 kW are installed at Esplanade substation. These machines 'pump in' current through negative cables from distant centres of the track and keep the voltage drop within the limits set by the Indian Electricity Act.

Recording voltmeters are installed in all stations to show that the voltage drop on the track does not exceed the amount specified, and to show up any faulty rail joints.

Line Equipment.

Current is collected by the tram cars from an overhead system through a trolley wheel. The trolley standard is adjusted so that the trolley wheel exerts a pressure of 23 lbs. on the trolley wire; this together with the V-groove of the trolley wheel ensures good contact. The trolley wire in use contains from 0·6 p.c. to 0·9 p.c. of cadmium which gives it a longer life than plain hard-drawn copper. It is grooved for holding in hangers and is aligned centrally over the track to minimise the screeching that usually accompanies this type of current collection. The style of the trolley wire varies according to that required by the traffic conditions of the area being served. The overhead network is suspended from stepped poles 33 ft. in height by means of stranded galvanised steel wire according to standard practice. Overhead line insulators divide the system into a number of sections fed by the feeders radiating from the sub-stations. These feeders feed into pillars situated at intervals along the line. Here, through knife switches they divide into four mains and the current is conducted up to the trolley wire and connected on the supply on both sides of the up and down lines. Thus, comparatively small sections of the line can be isolated in emergency, or alternatively any two or more sections can be looped together. and can receive the feed in spite of a cable breakdown.

Permanent Way.

Permanent Way practice had perforced to be changed with the increase in weight and speed of the vehicles. The present method of track construction follows closely that of the Metropolitan Electric Tramways of London. The standard sections of rails used in the system are 90 lbs., 96·4 lbs., and 103·7 lbs. per yd.; the lighter sections are being gradually displaced by the heavier section in all renewals. The rails are led over a concrete foundation 9″ thick, being separated from it by a ⅜″ to 1″ thickness of compressed bitumen boards, consisting of hessian layers thoroughly impregnated in bitumen and compressed. When placed under the rails they serve to reduce the 'roaring' which this type of construction produces. The rails are bolted to anchors (made up of old rails 7 ft. long), spaced 7 feet to 10 feet apart and embedded, flange uppermost, in the concrete foundation. The flange is cut away for a length of 3 feet in the centre of the track to enable it to be held solidly in position by the concrete. A mixture of 1 : 3 : 6 is used, and rapid-hardening cement is employed in order to save time and cause less inconvenience to the public during the curing of the concrete bed after the concrete has set the rails is bolted in position, levelling and alignment being done by means of the bitumen boards and tie-rods, which are positioned between consecutive anchors, respectively. The foundation is then covered over with rubble and metal which is rolled down, treated with asphalt penetration and finished with a sealing coat to give a roadway capable of with-standing present-day traffic conditions.

Joints between rails are supported on the underside by a ½″ sole-plate 2 ft. long and 8″ wide, and are held together on the sides by two 1″ fish-plates 18′

long, bevelled and grooved to fit snugly into the rails. The fish plates are held in position by two 4½″ × 1″ mild steel bolts, and small lengths of welding along the edges to give further mechanical rigidity. The sole plate is welded to the bottom of the rail, at the same time, to keep it in position, and the whole makes a solid assembly mechanically strong and electrically continuous.

Bonding of rail to rail and track to track is carried out at intervals of 60 feet along the route. Bonding to the overhead poles is also done at suitable intervals to ensure earthing.

Rolling Stock.

The rolling stock in service at the beginning of the year 1939 was as follows:—8 bogie trains, 22 single deck bogies, 137 single truck trains and 85 double deck bogies which include 19 of the centre entrance pattern.

Bogie trains consists of 2 cars, i. e., a motor coach and a trailer with a total seating capacity of 94. The motor coach is mounted on two Brush Maximum-traction trucks, each furnished with a Brush traction motor of 25 h. p. The trailer is a smaller car assembled on a Brush single truck, without any motive power. These units are not much in favour as they occupy a large road space, have a low acceleration and a high current consumption per car-mile.

i. Single deck bogies.

The motor coaches from the bogie trains are being dismantled and after remodelling are run as separate units where traffic conditions do not warrant the provision of greater accommodation. The seating capacity is 60. The motive power is the same as before but the disadvantages are to a large extent eliminated. (Weight in tons—unladen 12·88 ; laden, 16·03).

ii. Single truck trains.

Two single deck cars, each accommodating 36 passengers, are coupled together to form this unit. Each car is mounted on a Brush or Brill singletruck and equipped with Brush 25 h. p. or G. E. 35–40 h. p. traction motors. Like the bogie train, they take up a large amount of road space but otherwise have given good service. They are capable of an acceleration of 0·65 ft. per second per second. (Weight in tons—unladen 15·32 to 18·45; laden 18·99 to 20·46).

iii. Bogie double deck units.

Mounted on two Brush or L. C. C. maximum-traction trucks fitted with Brush 25 h. p. or Dick Kerr 30 h. p. traction motors respectively, these units are preferred by road users on account of their compactness. They are capable of seating 96 passengers and are economical in running. (Weight in tons—unladen 17·88; laden 22·88).

iv. Centre-entrance double-deck units.

As the name implies, these cars have doors positioned in the centre as against the back entrance and front exit of the other units, the doors being operated by compressed air. The doors are controlled from the driver's cab, so that dangerous boarding and alighting from a moving vehicle is prevented. The single step on to the car is another safety feature. Traffic signals indicate when the car is turning and when passengers are alighting, whilst the presence of a 'dead' car on the road is made known to other road users by highly efficient reflectors. The seating accommodation of this car is 94, but standing room for a further 10 p. c. is available on the entrance platform during rush hours. The

car is mounted on two English Electric maximum-traction trucks, each fitted with a 43 h. p. motor of the same make. All bearings are of the roller type which tends towards smooth and comfortable travel. (Weight in tons—unladen, 19.07; laden, 24.65).

Braking.

All double deck cars are fitted with air brakes. Hand-operated brakes are used as a stand-by and for parking, whilst the rheostatic brakes are used for emergencies. All other units are fitted with hand brakes for routine operation, and magnetic brakes acting on the track for emergencies.

Drive.

As all units are equipped with two motors, they are started with the motors in series through rheostats. The fourth notch on the controller cuts out all resistance and the motors are connected directly in series. The next 3 movements of the controller handle bring the motors in parallel through the rheostats. The cars can be driven from either end, but a power key on each controller enables them to be reversed if required. Turning the main handle in the reverse direction operates the rheostat or magnetic brakes. In case, one of the motors fails, it can be cut out and the car run into the car-shed for attention on the other motor." The highest fare charged is 2 annas, the minimum being one anna. Ratio of revenue to working expenses was 66.63 p. c. in 1937. (Transport World).

Fig. No. 31 shows a rectifier and a motor-generator installed at the Kingsway substation for traction supply; the photograph for this illustration was kindly supplied, alongwith the technical details quoted above, by the General Manager, B. E. S. & T. Co. Ltd. The number of units of electrical energy consumed for traction purposes by the B. E. S. T. tramcars rose from 4,780,793 in 1910 to 12,566,146 in the year 1938-39. Fig. 31 appears on page 88.

Delhi Tramways and Trolley-Buses (19/12/39).

"1 Traction Motor—series wound, 500 V, 19 h. p., B. T. H. Rugby.
2 Two motors per car. Series parallel control.
3 Route miles—5·134; single-track miles—8·080.
Trolley Bus—3 miles.
4 Gauge—metre. B. S. S.—1 equal to 6½ inches.
5 Weight—90 lbs. per yard; 96 lbs. on curves.
6 Length of rail section—45 feet.
7 Sectional area of trolley wire—3/0 and 4/0. Round section and Cottage loaf.
8 Composition—Hard-drawn (copper).
9 Rolling stock—26 single-deck cars; 3 trolley buses.
10 Total no. of vehicles—29.
11 Passengers carried in 1938. Trams—11,216,102; trolley buses 561,728.
12 Establishment—2 inspectors; 10 checkers; 4 starters; booking clerks; 2 timekeepers; 45 drivers; 72 conductors."

Fig. No. 27 shows one of the trolley buses used by the D.E. S.& T. Co., a description of which will be found in the next chapter. The fare charged by the Delhi Tramways is 3 pies or 1 pice for each stage or portion of journey, the minimum being half an anna.

Table No. 6.

STATISTICS OF TRAMWAY COMPANIES OF PRINCIPAL INDIAN CAPITALS.

Date	Capital	Mileage	Cars	Passengers	Car-miles	Rail Weight	N. B
28-11-39	Madras	$16\frac{1}{4}$ route	103	75,530 daily	8,840 daily		(1)
24-11-39	Calcutta	38, two tracks	315	$106\frac{1}{2}$ million (in 1938)		105·7 or 110 lbs. per yd.	(2)
21-11-39	Bombay	30·877	277	106,[illegible]69,085 (in 1938)	5,921,974 (in 1938)	90,96·4, 103·7	(3)
19-12-39	Delhi			(in 1938)		90,96 lbs. per yd.	(4)
(i)	Tramways	5·134	26	11,216,102			
(ii)	Trolley Bus	3	3	561,728			

N. B. (1) Madras Tramways are the Pioneer trams in the East, having begun running in May 1895; each car has two motors.

(2) Calcutta tramway gauge is $4'8\frac{1}{2}''$. Rail length–45'; B. S. S. 7 and 7 c.; Dick Kerr 550–V motors; establishment–6,000.

(3) B.E.S.T. tramway : staff—1799 in 1937; motor h.p.—25,30,35/40 or 43. Units used for traction in 1938–39—12,566,146. Fares—between 1 and 2 annas. Trolley wire size varies according to traffic requirements. Car weight unladen, from 12·88 to 19·07 tons; laden, from 16·03 to 24·65 tons.

(4) Delhi tramway : gauge—metre; length of section of rail—45 feet; establishment—137; trolley wire—3/0 or 4/0, round section and cottage loaf. Motor—B. T. H. 19—h. p.; 500—V; 2 motors per car.

(5) Fig. 26 is from a photograph in an English Electric Booklet, and Fig. 27 is from a photograph kindly lent by the General Manager, D. E. S. & T. Co. Ltd.

(6) The cost of a tram car may be considered as about Rs. 10,000.

The only method of current collection employed in India for railways or tramways is by means of overhead copper wires, one for each pair of rails. In France and Germany, the double-trolley system (in which two over-head conductors are used) is in vogue in certain cities. The third-rail method which is preferred in some places in Great Britain and elsewhere is referred to in the second and twelfth chapters of this book. The 3rd or insulated rail is usually on a slightly higher level than the other two rails, and may be either protected or unprotected. With the three-phase system, two overhead wires and the 3rd rail are used to supply current to 3 phase tramway motors. Conduit systems—open or slotted, and closed or surface-contact—are used in large cities only, being very expensive. In some places, a fourth rail is also used (with d. c. traction).

B. Overhead or Elevated and Underground or Subway Railways.

Owing to the drawbacks inherent in a rigid system like that of the electric tramways in large cities of the progressive and speed-loving West, 'scrap the trams' has become a slogan of several municipalities in England. Some cities e. g. Liverpool and New York, which had put up structures for running elevated or overhead trains over certain busy thoroughfares some time in the past, are still carrying on with them but it is merely a question of time when these will also share the fate of the tramways—recently a portion of the Elevated system in New York (Sixth Avenue-Manhattan) has been done away with, as it was found to impede the intensive life led by the go-ahead Americans. Consequently, recourse is being had to the petrol or gasoline automobile, the oil lorry or omnibus and the electrical vehicle (whether worked by current off trolley wires or off a storage battery), as none of these necessitate the insertion of rails in the pavement or the erection of stanchions in the middle of the highway of busy centres of population. Where frequent trains do (and will probably continue to) run on railways in cities like London, Glasgow, Moscow, Madrid, Brussels, Berlin, Paris, and New York, they are sub-surface or under the ground over which faster and more flexible forms of conveyances than tramcars move. Deep level electric railways have been in use in London since 1890. The London underground cars are 51′ to 52′ 6″ long and are provided with two electric motors, each 240 H. P.—a train of 1440 H. P. being made up of 3 motor-cars and 4 trailers, having a schedule speed of 25 miles per hour and capable of transporting 1600 passengers per hour: statistics may be seen in the last chapter of this book. For the purpose of conveying passengers from the ground to the rail-level in the case of the 'Elevated or El.' railways and from the platform to the road-level in the case of the 'Subways' or 'Underground or Tube' railways, escalators or automatically moving steps or stairs are usually provided wherever necessary; these have a speed of about 180′ a minute and a vertical rise of 90′ in some places. Noise inside tunnels is reduced by treating them with sprayed asbestos. Signalling is of the automatic colour-light type. Neither elevated nor underground railways exist in any city of India at present. Calcutta might have had a 'tube' under the Hooghly river (as New York has under the Hudson, and London under the Thames), had it continued to be the metropolis and gone on expanding in commerce, and if its population had grown at a rapid rate. There exists a tunnel under the Hooghly River for carrying the electric mains from the Southern Station of C. E. S. Corporation to Howrah Bank.

In Moscow, 128 million passengers were carried by the underground railways in 1937; 20 trains per day and 27 escalators—for a height of 130 ft. and a length of 210 yd.—being used.

CHAPTER X.

ELECTRIC VEHICLES FOR CITIES AND FACTORIES.

Railless Electric Traction—(i) Battery Vehicles.

Electrically-driven vehicles restricted to a rigid track on, under or over, the surface of streets having been dealt with in the preceding chapter, such vehicles not confined to a pair of rails but free to run over the whole unoccupied area of roads in cities or factories *i.e.* trackless trams and self-propelled vehicles, will now be considered.

Among the means of locomotion that depend upon electric current but dispense with the rails (whether on the ground or on elevated structures) and run on the road-surface (not under or over it) are the battery vehicle and the trolley bus,–the latter being otherwise known as the trackless trolley car, in contradistinction to the tramcar. In the case of the former, the required current is taken from the battery of secondary cells carried by the vehicle in the place where the petrol or oil engine is usually ensconced in an automobile or motor lorry. The battery vehicle is not often used by the public in general, being commonly employed in industrial workshops or factories and sometimes by well-to-do persons like the Princes,—being just the sort of conveyance for situations, *e.g.* pleasure drive, milk delivery etc., where the utmost cleanliness and quietness or comfort are of the first importance, and where facilities exist for charging the battery even at distances remote from the centres of activity. In Blackpool, Glasgow, Birmingham and Westminster (London), electrically propelled vehicles are also used for refuse collection. The radius of operation of passenger cars varies from 60 to 90 miles. The batteries usually consist of 42 cells of 2 volts each or 60 cells of 1.4 volts each—the ampere-hour capacity in either case being 100 to 500 Ah. The weight per cell varies from 13 to 48 lbs. for nickel-iron-alkali cells and from 27 to 124 lbs. in the case of lead-acid cells. The motor is usually of the 4-pole series-wound type : for some applications, two or four such motors are employed. Among the advantages of battery vehicles may be mentioned the following :—

1. Reliability. 2. Smooth running. 3. Low costs of (a) energy and (b) insurance. 4. Safe speeds. 5. Elimination of complicated mechanisms. 6. Saving of energy during coasting and braking periods. Besides being used on roads in cities and factories, battery vehicles are sometimes run on rails, *e. g.* the 21–ton 440–V battery

tenders for electric locos. in certain yards of the South Indian Railway near Madras and Tambaram. The cost of operation per ton of load collected of an electrical vehicle is less than that for a horse-drawn vehicle (8s.8d. against 9s.9d. *Electrical Review*, Oct. 1938.) and probably about three-fourth of that of a petrol vehicle.

(ii) Trolley Buses.

The only city of India where trolley buses have been introduced for the benefit of the public is the present capital of this country, viz., Delhi. If the Tramway Company of Calcutta carries out its idea to run trolley buses along Chittaranjan Avenue, Cossipore-Chitpore road, Maniktolla, Entally, Beniapurkar and Ballygunge, the old metropolis will be the second city to run trolley buses and it will do so on a larger scale than Delhi where only a couple of roads witness this comfortable form of street vehicle. There was a proposal before the City Municipality of Poona to introduce trolley buses but it has not materialised. Such a proposal had a greater chance of acceptance in the commercial Gateway of India, Bombay, where electricity can be had cheaply and in abundance, if the B. E. S. and T. Co. had not decided against their adoption for adequate reasons, having started oil buses to supplement its tramway services. On the other hand, Rangoon—the capital of Burma (which is the source of most of the oil and petrol in India)—has a fleet of trolley buses. One may therefore still cherish the hope that Bombay will sooner or later introduce trolley buses.

Advantages of Trolley Buses.

A trolley bus requires no permanent fixed track and is therefore flexible and fast. Such a bus can move laterally; it can circumvent the obstacles in its path; its trolley pole and shoe are so designed as not to come off the two overhead wires at speeds not exceeding 35 miles per hour (which is hardly ever reached in thoroughfares); it reduces congestion of traffic so often experienced in cities where trams run (perforce) along the middle of the road; it contributes to rapidity of transportation and growth of the area of a city as extensions can be made with little extra expenditure; it can be started without jerks; it costs less to repair and maintain than the trams as there are no rails to be renewed or pavements to be put right from time to time. Pneumatic tyres increase the rolling resistance which is naturally less in the case of trams that run on iron rails but being made of rubber, the tyres serve to insulate the electrical apparatus from the earth and prevent leakage of current which if allowed to go astray attacks metallic objects underground owing to electrolytic corrosion. As against the petrol and oil buses,

trolley buses are better because of absence of unhealthy smells from fumes and obnoxious gases; saving in running costs; prolongation of the period of renewals; faster getting away from rest without discomfort—single-deckers can accelerate at 5ft. per second per second and double-deckers at 3′ p. s. p. s.— ; lesse fire hazard; reliability and simplicity of operation; elimination of vibration and noise caused by reciprocating parts, gears etc.; and possibility of running satisfactorily in spite of temporary overloads. Above all, by the use of trolley buses, electricity locally generated is utilised in place of petrol or oil which have to be imported from places outside India which has no oil-fields except those at Attock in the north-west corner. A correspondent writing to the *Transport World* in June 1939 said that in London, passengers allowed oil-buses to go by and waited for trolley buses : a shilling-all-day ticket and a tourist ticket are available on the latter. In some places, batteries are used for manoeuvring trolley buses. (Acknowledgements are hereby made to 'Capital' of Calcutta and 'Electrotechnics' of Bangalore for matter utilised in this and other chapters.)

Types and Technical Details.

Trolley buses may have 4 or 6 wheels and one or two decks for seating 30 to 70 passengers; the latter type costing about £2000/– and the former about half as much. The average speed is about 12 miles per hour as against 10 miles per hour attained by tramways and the running cost is about 11 pence per car-mile compared with 13½d. for tramways. In Delhi, the 'Guy' single-deck, 20 m. p. h., 20 seat types, in which the 35 H. P. augmented field motor is in the midposition, are in use since 1934 (See Fig. No. 27). In Rangoon, fifteen 31–

Fig. No. 27. Trolley Bus in Delhi.
[Courtesy of D. E. S. & T. Co.

seater 'Sunbeam' buses were ordered in 1936, 18 'Ransomes' in 1937, and 30 'Ransomes' in 1938; they have a max. speed of 27 m.p.h. and are four-wheelers fitted with 35 h. p. series motors provided with field-regulating control and rheostatic braking. The driving motor may be one of the following four types :—a single series motor with field control (the field more heavily rated than the armature); two augmented-field motors with series-parallel and field controls but without differential gears (smaller motors and sufficient clearance); a compound-wound motor with shunt-field control and regenerative braking; and a motor similar to the last named but provided with rheostatic–as well as regenerative – braking;—the latter kind of braking is not effective at speeds of 12 to 15 miles per hour. The motors are fixed either forward (as in the Delhi buses and in the majority of cases), amidships or farther back (as in long vehicles). The Delhi Trolley buses have super-saturated series motors, giving powerful torque at starting. In the Delhi buses, regenerative braking is employed in addition to mechanical brakes. The foot pedal and hand lever work simultaneously all brake shoes in front and rear drums. Teak is used for the framework as it is immune both from white ants and wide variations in temperature. As many of the passengers are bare footed, extra precautions against leakage of current have been provided including a leak alarm indicator. The buses run from Paharganj to Birla Mills via Sudder, Tees Hazari and Sabzi Mandi. Some buses are fitted (among other appliances) with master controllers and separate manual operation of reversing gear: for suppressing interference with radio apparatus coils, filters or condensers are provided: two batteries of 24 volts each are utilised for lighting and for manoeuvring the bus when away from the supply line—the batteries being connected in series for the latter purpose and in parallel for lighting. The ordinary voltage at which the bus motor works is about 600 and the motor is one which is designed to produce a high starting torque. Such a motor would weigh about 1200 lbs. and develop upto 80 H. P. at 1100 r. p. m. The average annual consumption of energy is about 6000 units. The two trolley wires which supply current to the motor are usually spaced about 2 feet apart. They should be as far as possible over the central part of the bus but the latter should be able to collect current even when 12 feet aside from the wires. The sliding trolley shoe or bow collector (corresponding to the trolley wheel of the tramcars) is usually made of phosphor-bronze and provided with a detachable insert of carbon. In order to provide against effects of static electricity due to friction or induction, a large resistance is introduced in the earth circuit. In some places where tram-rails exist and two overhead wires are not

provided and where the single overhead wire is connected to the positive main and the negative lead is taken to the rails, the latter are touched by a 'skate' lowered from the chassis of the trolley bus to complete the circuit of the traction motor. The Delhi buses are not meant for heavy traffic: the unladen weight is $4\frac{1}{2}$ tons and the wheel base 15′1″, the drive being taken by means of a double propeller shaft to the rear axle. Other statistics may be seen in Table No. 6.

Petrol-Electric Trolley Bus.

Between Newark and New Jersey in the United States of America, an 'all-service' vehicle is in use. This is fitted with two 50 H. P. motors and works as a trolley bus wherever electric supply and overhead equipment are available. In places where these facilities for electrical operation are not present, the 125-H. P. petrol engine drives the generator in the vehicle to provide the current required by the motors. It can carry 36 passengers.

Electric Bicycles.

Electric Bicycles have been introduced in Holland. The electrical equipment, which consists of a 12-volt battery and a motor, weighs about 60 lbs. The bicycle can cover about 80 kilometres before needing a fresh charge for its battery.

Trolley Buses in other Countries.

In England, where the trolley bus was first introduced in 1908, over 790 route miles are covered by about 3800 trolley buses, of which about 2800 are double deckers: out of the total number about one third *i. e.* 1300 run in London, over 600 in Manchester District and the remainder in over 26 other cities. In the United States, the number of trackless trolleys ordered in 1936 equalled the number ordered during the preceding six years; over 17 routes covering more than 70 miles are served by them. Railless trolley cars are extensively used in several cities of Italy; their adoption was rapid when there was fear of petrol sanctions. They are also working in France, Belgium, Holland, Denmark, Poland, Germany, Russia, Norway, South Africa, Straits Settlement, Singapore, Japan, Shanghai (China), Australia, Canada, Peru (South America), Tasmania, Eire etc. The cost per trolley bus varies from £ 2,200 in Wolverhampton to £ 3,000 in Johannesburg (S. A.), where 55 of them have been ordered recently, (*Electrician*, 28-7-39).

The weight of trolley buses ranges from 3 cwt. to a little over a ton, the standard ratings being 7–9 cwt., 10–14 cwt. and 18–22 cwt.: a 2-ton lorry is in use for delivery of coal.

In U. S. A., the trolley bus vehicles costs were found to be as follows:—Operating expenses from 11 to 12½ cents, maintenance from 1 to 5·8 cents and power costs from 0·8 to 5·1 cents per vehicle-mile. In the same country, diesel-electric buses are in use in some cities *e. g.* Newark, Baltimore and Boston.

In Austria, a diesel-electric coach is used for inspection of trolley wires.

In Great Britain, there are about half a million electrical vehicles. In Italy, their number is on the increase ; Milan alone had about 460 and Turin 180.

In Eire (Ireland) not only are battery lorries and vans in use, but some trains are run by Drumm batteries; this new type of alkaline battery being made in 600 amp.-hr. units for traction purposes, 272 cells giving a voltage of 460 to 510 volts and weighing 15 tons : two electric motors, 200 h. p. each, drive the train. Such a train could be operated on the Mysore-Maddur-Bangalore section, as facilities for charging the batteries could be easily provided.

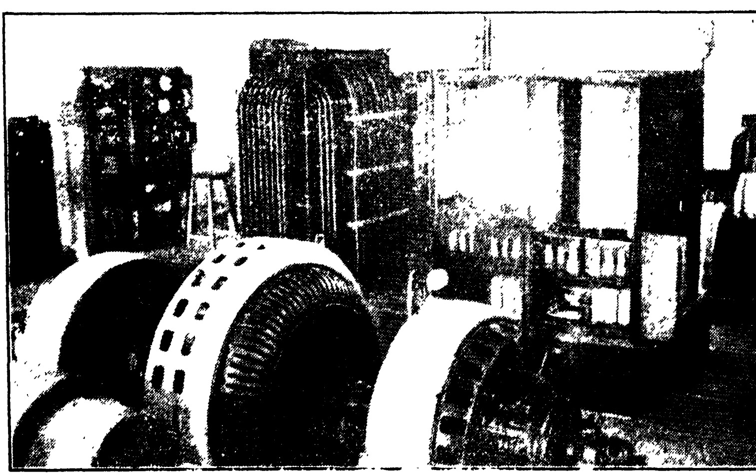


Fig. No. 31. Mercury Arc Rectifier and Motor-Generator set, in a Street Traction Substation at Bombay.

[Courtesy of B. E. S. & T. Co. Ltd.

CHAPTER XI.

ELECTRIC TRACTION MATHEMATICS.

Mechanical as well as electrical quantities and calculations are involved in the mathematics pertaining to electric traction. In order to form an idea of the power required to pull a train, both the force or tractive effort and the velocity or speed must be known. Power equals work or energy divided by time; and energy equals force multiplied by distance. Velocity being distance covered in a certain time, power equals force multiplied by velocity. Now the force or tractive effort which will cause a train to be moved depends upon the following :—

1. Frictions or mechanical resistances (these vary with the weight, velocity and cross-sectional area of the train and the number of carriages composing it); 2. Curves in the track; 3. Gradients on the way; 4. Acceleration to be produced to maintain schedule speed; and 5. Kinetic energy to be supplied to rotate the gears, armatures and other rotating parts. Tractive power, therefore, is tractive effort, T, (lbs.) multiplied by speed, v, (feet per second) or 0·00267 T V (h. p.), if V, speed, is expressed in miles per hour: see the formulæ etc. at the end of this book. The maximum tractive effort that can be exerted without causing the wheels to slip is usually about 22% of the weight on the driving wheels. N. B. This ratio is the coefficient of adhesion. The ratio of the weight on the driving wheels to the weight of the train is from 0·15 to 0·3 for steam trains and from 0·4 to 0·6 for electric trains, in the majority of cases. The influence of acceleration can be demonstrated by taking a concrete example mentioned, but not worked out, in Mr. Barnett's Paper, Bombay Engineering Congress, 1918.

Data—1. Stations, 0·5 mile apart, AC (in the figure shown); 2. Acceleration, a', 0·5 m.p.h.p.s. (which is usual with steam trains); 3. Acceleration, a'', 2 m.p.h.p.s. (for electric trains); and 4. Deceleration or braking, d, $-1·5$ m.p.h.p.s. (common for steam and electric traction).

A.................B.................C
$\longleftarrow S_1 \longrightarrow \longleftarrow S_2 \longrightarrow$

1 m.p.h.p.s. is 44/30 or 22/15 f.p.s.p.s.; 1 mile is 5280 feet.

Initial velocity may be denoted by u and final velocity by v. t', denotes the time for the distance AB or S_1, and t'', the time for S_2.

For AB, $v=u+at'$; for BC, $0=v+dt''$ $\therefore v=-dt''$, $\therefore at'=-dt''$, if $u=0$, as in the case of starting from rest.

$$S=S_1+S_2, S=ut+\tfrac{1}{2}at^2, S_1=\tfrac{1}{2}a(t')^2, S_2=vt''+\tfrac{1}{2}d(t'')^2=-\frac{d}{2}(t'')^2$$

$$\therefore S=\tfrac{1}{2}\left[a(t')^2-d(t'')^2\right].$$

Substituting $t'=-\dfrac{d}{a}t''$, $S=\dfrac{(t'')^2}{2}\left(a\dfrac{d^2}{a^2}-d\right)=\dfrac{(t'')^2}{2}\times d\times\left(\dfrac{d}{a}-1\right)$;

$d=-\tfrac{3}{2}$ *m.p.h.p.s.* $=-\tfrac{11}{5}$ *f.p.s.p.s.*

Case (a) viz. $a=0{\cdot}5$ *m.p.h.p.s.* or $\tfrac{22}{15}\times 0{\cdot}5$ *f.p.s.p.s.*,—steam train.

Case (b), $a=2$ *m.p.h.p.s.* $=\tfrac{22}{15}\times 2$ *f.p.s.p.s.*, —electric train.

(i) (a) $S=\dfrac{(t'')^2}{2}\left(-\tfrac{11}{5}\right)(-3-1)=\tfrac{22}{5}(t'')^2=2640, (t'')^2=600, t''=24{\cdot}5.$

(b) $2640=\dfrac{(t'')^2}{2}\times-\tfrac{11}{5}\times\left(-\tfrac{3}{4}-1\right)=\tfrac{77}{40}(t'')^2, (t'')^2=1371, t''=37{\cdot}1.$

(ii) (a) $t'=-\dfrac{dt''}{a}=3\times 24{\cdot}5=73{\cdot}5$ seconds.

(b) $t'=\dfrac{d}{a}\times t''=\tfrac{3}{4}\times 37{\cdot}1=27{\cdot}8$ seconds.

(iii) (a) $t=$total time$=t'+t''=73{\cdot}5+24{\cdot}5=98$ seconds.

(b) $t=37{\cdot}1+27{\cdot}8=64{\cdot}8$ seconds only.

(iv) (a) $v=-dt''=\tfrac{3}{2}\times 24{\cdot}5=36{\cdot}75$ *m.p.h.*

(b) $v=\tfrac{3}{2}\times 37{\cdot}1=55{\cdot}65$ miles per hour.

N. B.—Greater speeds are therefore possible with electric traction.

Force is mass multiplied by acceleration and is usually expressed in lbs. Velocity is expressed in feet per second. Their product, power, is therefore foot-pounds per second and work is ft.-lbs. Now, the tractive effort has been seen to be a fraction of the weight, usually expressed in tons and the velocity is so many miles per hour. Their product would be work or energy, in ton-miles, per hour. Energy can also be expressed in watt-hours. There is therefore intimate connection between ton-mile and Wh, which enables one to deduce the energy in electrical units, if the mechanical quantities are known. This will be illustrated when later in this chapter detailed calculations are given regarding curves of train performance and regarding the energy required by a train, for the particular problem to be solved, from the data relating to it and its motors,

Besides the mathematical methods referred to above, there is a way based upon actual experience with steam trains. Taking the figures from a Report on Railways in India, the consumption of coal, in one case, came to 220 lbs. per 1000 ton-miles, and the calorific value of the coal was probably 12,000 B. Th. U. per pound. Supposing that of this, a quarter is unutilised, being spent for shunting, standby losses, shop use, etc., and taking the efficiency from coal to wheel-rim as 4%, the energy for moving the trains amounts to $0{\cdot}75 \times 12000 \times 220 \times 0{\cdot}04/1000$ or $79{\cdot}2$ B. Th. U. per ton-mile. This is the same as $778 \times 79{\cdot}2$ ft.-lbs. or $778 \times 79{\cdot}2/1980000$ HPh, from which the energy in watt-hours is obtained by multiplying by 746; the result being $23{\cdot}2155$ Wh per ton-mile. From this, power in watts could be ascertained: and from the voltage of the traction motors, the current required by the train is calculated and therefrom the number and size of the motors fixed.

Train Performance Curves

More often, however, the characteristics of the traction motor (connecting tractive effort, speed and efficiency with current) and data relating to the motor, the train, the track etc. are used as the bases from which the curves of train performance are drawn. One of these curves connects current with time and its area, ascertained by the Planimeter or Simpson's Rule or merely by taking small strips of the area and adding their values together gives one factor of the product—the other factor being the constant voltage—which is the energy consumed. In order that the reader, who is keenly interested in this subject, may comprehend the procedure just outlined, a concrete example will be worked out.

Data :—Number of cars, n, is, say, one. Weight of car of 4 motors is 80 tons; weight per motor is therefore 20 tons; the total weight is W. Cross-sectional area, A, is 100 sq. in. Tractive effort to overcome train resistance is obtained from the formula given at the end.

$$T = 50/\sqrt{80} + .03v + .002 \times 100v^2/80$$
$$= 5.59 + .03v + .0025v^2 \text{ lbs. per ton.}$$

This is the value for a level portion of the track; in other words, for a 0% grade. N. B. $50/\sqrt{W}$ must not be less than $3 \cdot 5$ (Here it is 5.59). For each one per cent of grade, this tractive effort is increased by 20 (for an American ton) or 22. 4 (for a British ton), when rising. When going down hill, a similar amount should be substracted. Assume the road profile to be as follows:—2000 feet—0%

grade; 1100 ft.—+1% grade: 100 feet—+5% grade and 1000 feet—-3% grade. The value for tractive effort given above would therefore alter as regards the first term of the three terms comprising it, which would be 5.59 for 0% grade; 25.59 for 1% grade; 105.59 for 5% grade and -54.41 for -3% grade.

Other data are:—Voltage-500 V; H. P.-160; Current at starting-275 A; Armature-1 turn; Field-large spool-62 turns, small spool-29 turns; Diameter of wheel-33″; Gear-55; pinion-18; gear ratio-3.05.

Explanatory Note

From the motor characteristics (see graph sheet attached, Fig. No. 28), the tractive effort corresponding to various values of current is got and dividing this by 20 (since each motor weighs 20 American tons), the tractive effort per ton is obtained. Deducting from this the train resistance and grade tractive effort, we get the net value. The formula connecting this with acceleration is T=W x a/g, g being acceleration due to gravity, generally taken as 32, and a being the acceleration of the train in feet per second per second. If a is in miles per hour per second, multiply by 5280/3600 or 22/15; if W is in tons and tractive effort is required in lbs., multiply by 2000 for American, and by 2240 for British value of ton in lbs. Taking for simplicity's sake, 2000 in the above equation, T would be 2000 x 22 Wa/32 x 15 or 275/3-Wa. Vice versa, a would be 3/275-T/W. The acceleration would therefore be got, from the tractive effort per ton (net) by multiplying it by nearly ·011 or (3/275), in miles per hour per second. The speed characteristic enables one to ascertain increments of speed by subtracting consecutive values. From increments of speed and the corresponding average acceleration, increments of time are known (t=v/a). By adding consecutive values of increments of time, the total time is obtained. Similarly, increments of distance in feet are obtained by multiplying the average velocity by the time increments and by the factor 22/15 or 1.47, to change from miles per hour into feet per second. Then the total distance is got by adding the increments of distance. The current, speed and distance are plotted against time to get an idea of the performance of the train.

To calculate the energy, the area under the current-curve is multiplied by 500 (the value of the voltage); but this being in watt-seconds has to be divided by 1000 x 3600 to get the answer in kWh, or Board of Trade units of electrical energy.

TABLE No. 7.
Train Performance Calculations.

Amps.	Tractive Effort per Motor.	Tractive Effort per Ton.	Tractive Effort for Train Resistance.	Average Net Tractive Effort.	Aver. Accel. m/h/s a	Speed m/h v	Incr. of Speed Δv	Incr. of Time Δv/a	Total Time t	Incr. of Dist, Δs	Total Dist. ft. s
275	(a) 0% grade, 3650	2000 ft. 182·5	5·59	176·91	1·948	0	—	—	0	—	0
					1·9415	8·125	16·25	8.47		101.2	
275	3650	182·5	6·7375	175·7625	1·935	16·25			8·47		101·2
					1·8225	16·55	0·6	0·3292		8·015	
250	3250	162·5	6·8055	155·6945	1.71	16·85			8·8		109·215
					1·4755	17·625	1·65	1·15		29·8	
200	2400	120	7·001	113	1·241	18·5			9·95		159·02*
					1·0159	19·3	1·6	1·575		44·7	
150	1580	79	7·19	71·81	0·7898	20·1			11·525		203·72
					0·5721	22·05	3·9	6·82		221	
100	800	40	7·75	32·25	0·3544	24			18·345		423·72
					0·2709	25·75	3·5	12·9		488	
75	500	25	8·3	16·7	0·1874	27·5			31·245		911·72
					0·1707	28·05	1·1	6·45		266	
70	450	22·5	8·493	14·7	0·754	28·6			37·395		1177
					0·129	29·3	1·4	10·4		433	
65	400	20	8·74	11·26	0·124	30			47·795		1610
					0·10925	30·45	0·9	8·4		369	
62	350	17·5	8·9	8·6	0·0945	30·9			56·035		1979
62	(b) 1% grade, 350	1100 ft. 17·5	28·9	−11·4	−0·1252	30·9			56·035		*1979*
					−0·1104	30·45	0·9	8.15		365	
65	400	20	28·7	−8·7	−0·0956	30			64·185		2344
					−0·0808	29·3	1·4	17·45		751·5	
70	450	22·5	28·493	−5·993	−0·066	28·6			81·635		3095·5
70	(c) 5% grade, 450	100 ft. 22·5	108·493	−85·993	−0·946	28·6			81·635		*3095·5*
					−0·9315	28·05	1·1	1·81		48·7	
75	500	25	108·3	−83·3	−0·917	27·5			83·445		3144·2
					−0·899	27·65	0·9	1		29·8	
80	560	28	108·158	−80·158	−0·881	26·6			84·445		*3184*

* **A slight error has crept in here inadvertently, but the sequence is clear and correct.**

(*d*) — 3% Grade, 1000 feet. N. B.—Current switched off. 3184' is nearly 3200', the peak of the grade.

Coasting, v = same as when Current was cut off = 26·6.

0	0	0	—51·842	51·842	0·57	26·6			84·445		3184
					0·568	27·6	2	3·52		146	
0	0	0	—51·507	51·507	0·566	28·6			87·965		3330
					0 565	29·3	1·4	2·482		107	
0	0	0	—51·3	51·3	0·564	30			90·447		3437

Braking, upto destination, for a distance of 4200—3437 = 763 feet,

0	0	0	0	0	0	30			90·447		3437

(Time required to come to halt, 763|30 × 1·47 = 17·3 seconds)

								17·3	107·747	763	*4200*

Table No. 8. Time-Speed-Distance / Current Curves.

(Total Current would be four times the value given in Table No. 7, as there are 4 motors in the car.) (Amps. 1100 is for 4 motors = 4x275)

Motors to be in series-multiple for half of the first interval of time, during which the current would be 2 × 275 = 550.

AMPS.	TIME	SPEED	DISTANCE	AMPS.	TIME	SPEED	DISTANCE
550	0	0	0	400	18·345	24	423·72
550	4·235			300	31·25	27·5	911·7
1100	8·47	16·25	101·2	280	37·4	28·6	1177
1000	8·8	16·85	109·25	260	47·8	30	1610
800	9 95	18·5	159	248	56	30·9	1979
600	11·525	20·1	203·72				
(The above are for the 0% grade—248 amps. is for 4 motors = 4x62)							
(For the 1% grade...............)				(For the 5°/₀ grade......................)			
260	64·2	30	2344	300	83·45	27·5	3144
280	81·635	28·5	3095·5	320	84·45	26·6	3184
(Coasting, -3°/₀ grade)				(Braking at 51.3 lbs. / ton)			
0	88	28·6	3330	0	107·75	0	4200
0	90·45	30	3437	0	0	0	0

From the above values, the curves of train performance are drawn, see Fig. No. 29. The area under the current-time gives coulombs or ampere-seconds. Taking small strips of this area, we get the following figures, *see* Table No. 9 :—

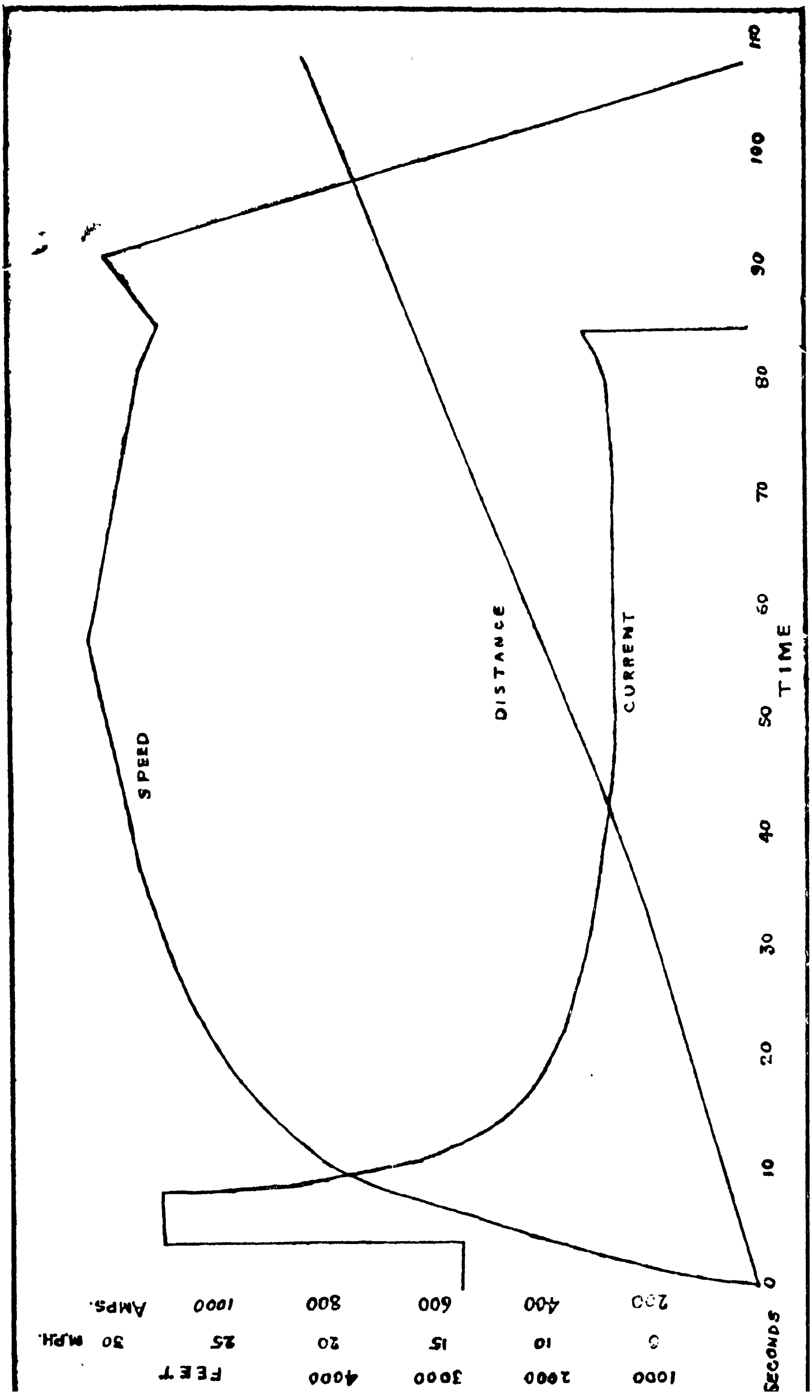


Fig. No, 29. Train Performance Curves.

Table No. 9

Determination of Ampere-seconds.

Increment of Time	Average Current	Ampere-seconds	Increments of Time	Average Current	Ampere-seconds
4·235	550	2330	5·6	275	1540
4·235	1100	4660	4·8	265	1281
0·33	1050	347	8·2	254	2080
1·15	900	1035	8·2	254	2080
1·575	700	810	7·8	264	2060
3·475	533	1850	9.635	274	2635
3·345	433	1448	1·815	290	526
7·655	365	2792	1	310	310
5·25	315	1655			
6·15	290	1782	84·45	Total	31221

From the value for quantity of electricity obtained just now, the value for energy is obtained by multiplying it by 500, the voltage. This, however, gives us watt-seconds. To get units of electrical energy i. e. kilowatt-hours, this must be divided by 1000 x 60 x 60. We therefore get 31221 x 500/1000 x 3600 or 4.345 kWh. From the mechanical and other data, we have thus got the amount of electrical energy required for the operation of the train.

Determination of Generating Plant Required

From the above calculation, the energy per cycle is seen to be 4·345 kWh or 4345 Wh. Distance travelled per cycle is 4200 feet or 35/44 mile, approximately 0·8 mile. Weight of the car is 80 tons. Watt-hours per ton-mile, therefore, equal 4345/80 × 0·8 or 68·28. The energy per car-mile amounts to 4·345/0·8 or 5·43 kWh. These are for a distance of 4200 ft.; for other distances, similar calculations give energy per ton-mile or per car-mile. It will be clear that this becomes less as the distance between stops becomes larger, owing to the energy for the acceleration period becoming a small portion of the total energy. A curve connecting energy per ton-mile with distance between stops can now be drawn; it will resemble to some extent the speed-current characteristic of the motor, see Fig. 28. Knowing the number of the cars and the schedule speed, curves of this kind give a measure of total power required; and load curves enable one to fix the number and size of the generators, by showing the varying demands of trains at different times of the day.

General Equations Regarding Schedule

Schedule speed has just been referred to. The following equations pertain to the schedule or time table.

P—estimated number of passengers (say 600)
Q—number of hours to carry P (say 2)
M—number of people one car will accommodate (50).

D—distance in miles (say 10)

T—time for a single trip of distance D, in minutes (say 30)

S—schedule speed in miles per hour—$D \times 60/T$ (seen to be 20)

N—number of cars required per hour (see below)

H—Headway, time between cars, in minutes (should enable a car to go a distance D and come back the same distance, before its successor starts—total distance 2D)

$\left[Q-(T/60)\right]$—no. of hours during which passengers must all start (works out $2-0{\cdot}5$ or $1{\cdot}5$)

$P/\left[Q-T/60\right]$.—no. of passengers to be carried each hour ($600/1{\cdot}5$ or 400)

N—no. of cars per hour is obtained by dividing this by M; which gives 400/50 or 8.

H—2T/N or $2\times30/8$ or $7{\cdot}5$ minutes. ($H=120D/SN$)

....

Other problems bearing upon electric traction need not be given as they are to be found in most text-books dealing with this subject. For the same reason, graphs and diagrams relating to the multiple-control and other systems, and to connections of motors and switch-gear in circuits are not included among the illustrations.

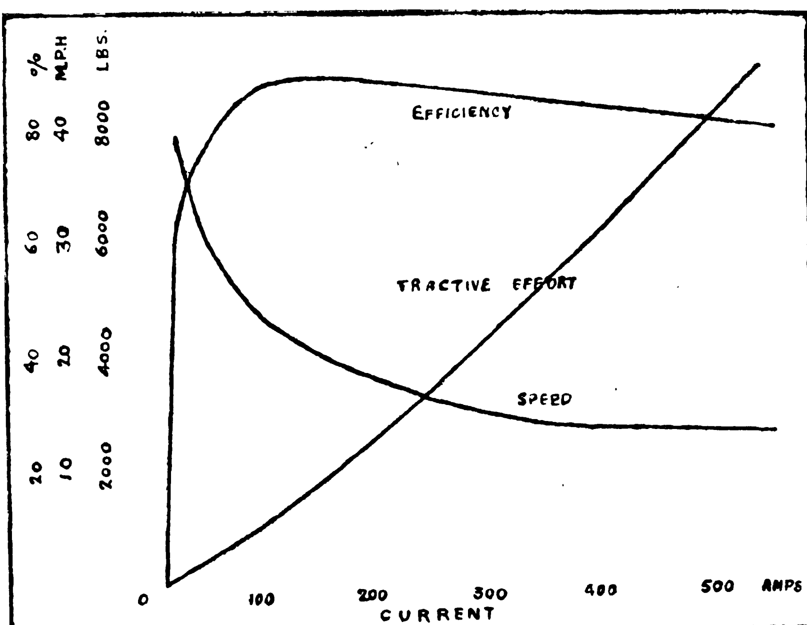


Fig. No. 28, Traction Motor Characteristics.

CHAPTER XII.

LATEST INFORMATION. SUPPLEMENTARY NOTES.

A. Indian Railways.

The statistics tabulated below have been taken from letters received from the Agents of the B. B. & C. I. Ry., and the S. I. Ry., and from the Annual Report of the G. I. P. Ry.

N. B.—(Energy units are kWh; power units, kW.)

Table No. 10.

STATISTICS *re* ELECTRIFICATION, INDIAN RAILWAYS.

ITEM.	B. B. & C. I. Ry.	S. I. Ry.	G. I. P. Ry.	
Year	1938—39	1938—39	1936—37	1937—38
Energy purchased, traction ..	31,825,907	6,177,479	66,101,700	67,400,890
,, ,, , other purposes ...			6,879,750	6,736,710
, ,, , total ...			72,981,450	74,137,600
,, supplied by Kalyan P. H. for traction, kWh) ..			46,365,064	46,081,789
,, ,, , ,, other purposes ...			980,786	1 015,211
,, ,, , total ...			47,345,850	47,097,000
,, for traction from both) sources, total units) ...			112,466,746	113,482,679
Highest ½-hr. max. from) Supply Cos. (killowatts) ...	16.000		16,880	17,280
Total Units generated (P. H.) ..			50,371,448	50,251,335
,, ,, sent out ,, ,, ..			47,345,850	47,097,000
,, ,, used in P. H. ..			3,025 598	3,154,335
Max. Load observed, kW ...			19,400	20,000
,, units sent out ½-hr. × 2 ...			12,200	13,600
Avg. ,, generated per hour ..			5,750	5,736
,, ,, used on wks ,. ,, ...			345	360
Calorific Value of Coal ...			B.Th.U.9508	9,396
Equiv. Coal per unit generated. ...			lbs. 2,016	2,061
,. ,, ,, ,, sent out ...			,, 2,150	2,200
Over-all Thermal Effy. per) unit generated, %) ...			17.82	17.63
Load Factor (Units sent out × 100) (Max.hourly ,, ,, ,, × 24 × 365)			% 44.3	39.5
Rolling Stock, Motor Coaches ...	40		53 (and 153 trailers)	
Avg. No. on line (units) ...		24		
,, ,, under repairs ,, ...		2.5		
,, ,, in use daily ,, ...		17.1		
,, ,, spare or stored ,, ...		4.4		
Failures in supply :—				
Originating at source ...		1	1 (P. H.), 13 minutes	
,, ,. substation ...		7	3,-3 minutes each	
On account of overhead) ... Equipment over track) ..		27	50 faults* (12 to over- head	
On account of motor coaches ...		26	*	

* 12 due to overhead equipment, 9 due to birds, 7 to lightning and 22 to other causes ; 18 coaches scheduled for replacement (9 placed in service ; 9 built, being wired); scheme for converting substations beyond Kalyan to unattended operation sanctioned, indents being submitted for approval.

In the Table that follows, particulars regarding mileage, net earnings, capital, working expenses, etc. of the three Indian railways which have been partly electrified have been given, as also of one of the unelectrified railways—the East Indian Railway—about which some information was given in the first chapter. The earnings of the Indian State Railways were Rs. 288 lakhs (approximately) in 1938–39 and Rs. 287 lakhs in 1937–38; the working expenses being about Rs. 500 lakhs. The rolling stock programme for 1940–41 provided Rs. 160 lakhs for locomotives and boilers, 132 lakhs for wagons, and 96 lakhs for carriages, making a total of 388 lakhs. The revised total comes to about Rs. 460 lakhs.

Table No. 11

INDIAN RAILWAYS—MILEAGE, EARNINGS, ETC.
(Indian Year Book, 1939–40).

Railway (Name)	Mileage (miles)	Capital (Rupees)	Earnings (Net) (Rupees)	(Net) %	Expenditure (Rupees)
G. I. P. ...	3727.16	1,14,75,29,000	4,28,92,000	3.74	
B. B. & C. I. ...	3509.16	73,33,87,000	5,09,16,000	6.90	
S. I. ...	2532.00	45,68,62,000	1,76,00,000	3.85	
E. I. ...	4390.80	1,48,18,38,000	8,25,52,000	5.57	
Total ...	43,118	8,79,57,33,000	32,90,29,000	3.74	70,93,88,000

N. B. — The figures for subsequent years are slightly different.

From the *Indian* Railway Report for 1937–38 summarised in the "*Engineer*" for April 14, 1939, it is learnt that the receipts of the State-owned railways amounted to 95.01 crores of rupees, 521 millions of passengers travelled over 41,076 miles and 105 passengers and 18 employees lost their lives.

The following facts and figures are reproduced, with thanks, from the *Journal* of the *Institution* of *Locomotive Engineers* for Sept.-Oct. 1939, as they pertain to the electrified sections of the B. B. & C. I., and the G. I. P. Railways :—

Mr. R. C. Case :—"Some 6 years ago, the B. B. & C. I. Ry. were successful in applying brake lining material to the wearing surfaces of bogie bolster rubbing blocks on electric suburban units.

Mr. Hoyle (L. A.) :—The passenger engine driving axle bearings are partially protected (by spring pads) and the average failures are about 7 per annum with a tendency to decrease, having been only 3 during 1938. On multiple-unit stock similarly protected, one hot bearing was experienced during the past seven years. The freight engine axle bearing are not *dust* protected; we have averaged 30 hot bearings a year during the past three years. The average of 3 years for engine miles is as follows:—

Electric Passenger Engine miles per annum	...	1,410,000
„ Freight „ „ „ „	...	1,146,000
„ Multiple Unit „ „ „	...	3,348,000

The increases during the past year have been as follows:—

Freight engine miles per day, now 130, have increased by	...	30
Through trains, speed 21 to 22 m. p. h. „ „	...	3,
All freight trains „ 17 „ „ „	...	2.

The first 10 freight engines had crankpins of case-hardened steel, and after 150,000 miles we could not measure any wear at all. The last 31 engines had crankpins of class C steel. There had been wear up to 15/1000 in. taper and 12/1000 in. oval, after 130,000 miles: the shoulders had worn back by ¼ in.".

Every progressive city desired now-a-days to go in for electric traction, on account of the enhanced speed, safety and comfort made possible by the adoption of vehicles which can travel at an average speed of 25 miles per hour and accelerate at the rate of nearly 3 miles per hour per second. London, the first city of the British Empire, stretches to a length of about 25 miles across, whereas Berlin, the capital of Germany, can not extend beyond 12 miles because it will not scrap its trams. The growth of London has however been rather lop-sided, owing to the Railways north of the River Thames not electrifying their lines to the same extent as the Southern Railway has done. Calcutta, the first city of the Indian Empire, has neither electric trains nor trolley buses. In even large Indian States *e. g.* Hyderabad (Deccan), Kashmir, Mysore etc., there are no electric trams, trains or buses.

"No system in Calcutta (which is still deprived of electric railways) can be entirely satisfactory unless it can cater for the business quarter of Clive Street and the students round College Street. The new Howrah Bridge is not to carry a railway and how trams are to carry 600 passengers tumbling out of a single train is a problem which defies solution. Some use could be made of the Bally Bridge but Sealdah is still a long way off from Clive Street. An overhead railway apparently can not be justified and it is certain that a tube cannot. We have good authority for this statement.' *Indian & Eastern Engineer, December 1936.*

The revised estimates for Indian Railways for 1938–39 and the budget for 1939–40 showed a surplus of £1,500,000 in each case. A sum of 3¾ millions was allocated to new rolling stock. The capital expenditure was estimated at £ 8¼ millions, including ½ million for new lines in Sind. The traffic receipts were expected to amount to £ 71,000,000. These are £ 250,000 less, and the working expenses are expected to be £500,000 more, than during the previous year. India's comparative industrial backwardness having once again become evident since September 1939 when the European War started, it seems highly probable that in future fifty steam locomotives will be built every year in India. The manufacture of electric locomotives in India is however another matter; of that one sees no signs whatso-

ever. The making of motorcars is still a dream, being merely the subject of talks, in this country. Diesel engines are being made in at least two places in India, a compressed ignition type at Satara and a high speed vertical type at Kirloskarwadi. It would be well to evolve a vegetable oil fuel suitable for Diesel engines to obviate the necessity of importing mineral oil. Only Assam in N. E. India, and Attock and Pabbi in N. W. India produce petroleum: India has to import large quantities of it.

The following facts and figures relating to Indian Railways have been gleaned from *The Indian and Eastern Transport*, February 1936 (which got the information from the Presidential Address in the *Journal of the Institution of Locomotive Engineers* for September-October 1935), and from Statistical Abstracts for 1938*:—

Table No. 12

INDIAN RAILWAYS—LOCOMOTIVES, VEHICLES ETC.

Indian railways are operated with :—

	1933-34	1935-36*	1936-37*
Steam Locomotives ...	9,248	8,961	8,863
Electric locomotives ...	75	75	73
Rail Motors ...	40	46	45
Steam coaches ...	35	33	41
Internal combustion coaches, etc. ...	4-out of 7536	7,413	7,567
Electric motor Vehicles...	117	118	118
Coaching Vehicles ...	20,753	20,094	19,875
Goods Vehicles ...	223,830	233,168	231,479

and a total staff of 701,362, of which 3,906 are Europeans.

The cost of coal, including freight, varied on different railways from Rs. 4.73 per ton to Rs. 19.7, freight charges from pit to running shed accounting for the major part of the difference in cost.

The calorific value of the coal varied from 11,660 to 13,333 B. Th. U. per lb.

On Indian broad gauge railways, coal consumption for the year 1933-34 was 126.3 lbs. per 1000 gross ton goods miles.

Electrification of railways in India has been introduced on a moderate scale with a route mileage of 181.7 miles on the G. I. P. Railway, 21.25 miles on the B. B. & C. I. Railway (37 miles now) and 18.14 miles on the South Indian Railway.

Lower density of passenger traffic on the longer electrified mileage of the G. I. P. Railway appears to be the reason for their more unfavourable train mile results than on the B. B. & C. I. Railway and the South Indian Railway.

It is perhaps interesting to note that while the passenger train mile cost of one of the broad gauge railways electrified in Bombay is given as Re. 1.16 per train mile, the passenger train mile cost of one metre gauge steam-worked railway is given as Re. 1 per train mile. (Train miles — steam, 175,533; electric 2,144. St. Abstracts).

The average tractive effort of all the steam locomotives running on broad gauge railways approximates 25,250 lbs. An average of 107 miles per day was obtained on all Indian broad-gauge railways for 1933-34.

(A dynamometer car is employed for tests on certain Indian railways.)

A metre gauge passenger locomotive when in first-class order consumed 9 tons of coal. The same loco. after running 65,000 miles (during which time repairs were neglected) was found to be consuming 11 tons for the same trip."

B. Electric Traction in Other Countries.

London's *Underground* Electric Railways cover 180 miles, have 226 stations and carry more than a million passengers per day. Some 2800 trains pass through Charing Cross station every week-day, After 40 years of steam, the Metropolitan and District Railways were equipped for operation by electricity. One sub-surface railway, the City and South London Railway, had been using electricity for motive power since 1890. (*Overseas Engineer*, January 1934). Great extensions of underground railways led to the formation of the Underground Electric Railway Company of London, Ltd. in 1902.

Table No 13

LENGTH OF ELECTRIFIED LINES.

Italy	5,100 Kilometres		3,200	miles
United States of America ...	...	... ...	2,700	„
Sweden	3,350 „	(3700 km. in 1939)	2,200	„
Germany	3,200 „		2,000	„
France	3,100 „		1,900	„
Switzerland	2,400 „		1,800	„
England (U. K.)	1,150 „		1,000	„
Russia (U. S. S. R.)	... ...	... ...	950	„

N. B.— The above figures are taken from *Electrical Review*, September 30, 1938, and from B. T. H. *Activities* for April 1939. The corresponding figure for India is 237 miles, or 379 kilometres; G. I. P. Railway has 182 route miles or 571 track miles electrified so far. Pennsylvania Railroad, U. S. A., had 364 route, and 1405 track, miles of electrified lines in 1936. For the world, the figures are 16,500 route, and 26,000 track, miles, *vide Railway Year Book*, 1938-1939. In Italy, it is proposed to electrify 1250

miles of steam railway lines. In South Africa, the mileage of electrified lines amounts to 590 route, 1217 track, miles. The Southern Railway of England has 702 route, 1742 track, miles of electrified lines, the cost being £ 20,500,000, the number of sub-stations 158, combined capacity of the latter 484,000 kW, the no. of vehicles 3189, train-miles per year 41,250,000.

" Italy has a longer electric railway system than any other country in the world with the exception of U. S. A. The State Railways operate 2430 route miles, and the private companies 520 miles, by electric traction (making a total of 2950 miles). It is now possible to travel from end to end of the peninsula by electric trains. The distance from Modane (the Mt.-Cenis frontier station) to Reggio (in the 'toe' of Italy) is 905 miles, equivalent roughly to the distance from Brighton to Glasgow and back. High average speeds are maintained.". (*Statesman*, Calcutta, 15-3-39). The voltage of suburban lines in Germany has been raised to 900 V from 800 V: that of Hamburg suburban lines has been altered from single phase to 1200 V d. c.

The " Times " *Trade and Engineering* monthly for August 1939 reports satisfactory progress in connection with electrification of railways in England, where over 7400 electric locos. and cars are now in use. In Kent, 54 miles of track have been electrified. The extensions include:—16 miles Otford to Maidstone East; 19 miles Gravesend to Maidstone West; 19 miles Swanley to Gillingham. New Tube stations at Highgate; tunnel 2 miles for Tube service from Archway Highgate to East Finchley. From East Finchley to West Central London and the City, 200 trains a day—during busy traffic hours at intervals of 4 minutes only. The Manchester-Sheffield-Wath main-line electrification, which is now in hand, will be completed soon. The route of this English railway can be seen in Fig. 30, for the block of which the Author is indebted to the *Indian and Eastern Engineer*, Calcutta.

The Wirral line of L. M. S., and the Central line of G. W., railways have also been electrified. Ten railways have been electrified in Russia: the Kirovsk railway is 300 Km. long: on the Yaroslav railway, 93,700,000 passengers travelled in 1937. In U. S. A.,

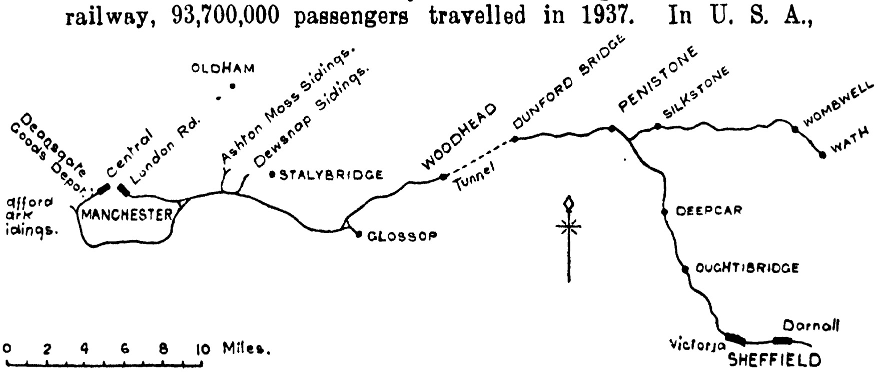


Fig. No. 30. Manchester-Sheffield Electric Railway Line.

[Courtesy of '*Indian and Eastern Engineer*'.

1,964,900,000 passengers travelled by electric trains; 554,600,000 by street cars and 609,100,000 by buses, in the same year. In Canada 631,894,662 passengers used electric railways in 1937. (*Electrical Review*, February 1939).

From the Proceedings of the Institut ion of Mechanical Engineers for Oct.-Nov. 1926, it appears that the electrification of the *Kalka-Simla* hill railway was proposed but not carried out. Mr. T. A. F. Stone of the N. W. R., Lahore in his paper on '*Electric Locomotives*' (from which the following Table has been reproduced) chose 3 p. c. grade and 16 m. p. h. to correspond with conditions existing on, or deemed desirable for service on, the Kalka-Simla Railway. The Table is based upon the following assumptions besides those just mentioned—0-4-4-0 type locos., adhesive weight 40 tons, axle-load 10 tons, trailing train load 115 tons, starting tractive effort (¼ of adhesive weight) 22,400 lbs., tractive effort for 3 p. c. grade and 16 m. p. h., 11,720 lbs., and horse-power for this duty 500. (These locos. are 66 p. c. more powerful than the locos. then in use on the Kalka-Simla Railway). The abbreviations stand, respectively, for the expressions written against each, herebelow :—

S. P. S.—Single-Phase System; D. C. S.—Direct Current System ; T. P. S.—Three-Phase System ; H. P.—Horse Power ; W.—Weight ; A.—Adhesive weight. N. B. The HP is taken as 20 times (on the average) the grate area in sq. ft. for the steam loco. (Prof. Dalby opined 30 as more correct), and equal to the one-hour H. P. rating of the electric loco. W is the weight of the loco. in tons, in working order. A is the adhesive weight in tons of the loco. in working order and E is the weight of motive power equipment in tons (for the steam loco., the weight of the boiler, water, coal, pipes, cylinders, pistons, rods and motion; for the electric loco., weight of motors and electrical equipment). Average values of 92 steam and electric locos. are given.

Table No. 14.

CLASSIFICATION OF STEAM AND ELECTRIC LOCOMOTIVES.

Type of Loco.	HP/A	HP/E	HP/W	E/W	A/W
Passenger Steam ...	15.4	12.85	5.67	0.443	0.375
„ S. P S. ...	23.7	32.9	16.26	0.499	0.688
„ D. C. S. ...	24.78	46.5	18.8	0.404	0.78
„ T. P. S. ...	44.2	...	33.9	...	0.79
Goods Steam ...	10.96	12.00	5.7	0.476	0.528
„ S. P. S, ...	14.34	27.06	12.03	0.459	0,85
„ D. C. S. ...	15.4	41.9	14.9	0.358	0.97
„ T. P. S. ...	27.8	...	27.8	...	1.00
Shunting Steam ...	9.03	14.43	6.31	0.438	0.701
„ S. P. S. ...	10.53	21.93	10.53	0.482	1.00
„ D. C. S. ...	8.77	22.18	8.77	0.403	1.00
„ T. P. S. ...	14.15	30.9	14.15	0.475	1.00
Motor Coach Steam ..	12.37	17.4	4.18	0.24	0.337
„ „ S. P. S. ...	12.66	27.4	8.45	0.316	0.720
„ „ D. C. S. ...	14.53	51.4	12.2	0.218	0.85

Vol. 236 of the Proceedings of the Institution of Civil Engineers contains papers on 'Electric Trains with frequent stops,' 'Electric Rolling Stock for Intense Service,' and last but not least 'Steam,

Electric and Diesel-electric Traction'—the latter being of value as it draws comparisons between the three methods, with special reference to Great Britain.

Combination type electric locomotives are widely used in goods stations and on certain portions of industrial lines. They are combinations of a straight electric locomotive with either a diesel-electric or a battery locomotive; the voltage in the latter case being 60 to 80 volts. Combined battery and third-rail locomotives are used by London Transport for maintenance and constructional work on the tube and surface sections; the batteries being charged from the third rail. Such locos. operate at low speeds. London Transport also uses portable pumpless air-cooled steel-clad rectifiers of 250-kW capacity.

Having given above a comparative Table regarding steam and electric locomotives, it seems advisable to mention the estimated working costs of steam and electric railway working, as printed in the May-June 1939 issue of "*B T H Activities*," vide Table No. 14 (a).

Table No. 14 (a)

WORKING COSTS OF STEAM AND ELECTRIC RAILWAY WORKING.

	For Steam Railways		For Electric Railways	
	per train-mile	Total	per train-mile	Total
Operating Costs ...	23.8 d.	£33,688,000	16.3 d.	£23,067,000
Maintenance Rolling Stock...	6.0 d.	£ 8,505,000	2.5 d.	£ 3,546,000
,, Substations and Overhead Equipment				£ 3,232,000
Auxiliary Power Supply ...		£ 1,500,000		£ 750,000
Total ...		£43,693,000		£30,595,000
Saving due to Electrification		£13,098,000		

Cost per track-mile, £ 3,670 in Italy; £ 8,650 for Swiss Federal Railways; £ 7,500 suggested by the Weir Report, which states that electric traction has definite superiority over steam traction.

The electric train service at Liverpool (Wirral Peninsula) has the following novel features:—

1. Light rolling stock (19 three-car trains, steel bodies welded to the underframe).
2. Motor coach, 4 motors, 1135 h. p.
3. Air-operated sliding doors, controlled in the first instance by the guard but also by push-buttons on the doors, to avoid exposure of passengers during bad weather.

4. Electric undergear can be removed quickly at rail level on special trolleys in concrete sheds.

5. One control station and a series of robot substations remote-controlled by 2 men from Birkenhead North.

6. Live *third-rail* receives current at 650 volts from Liverpool Corporation by 2 feeder cables, 5800 yds. long, through a tunnel under the Medway river.

7. Conductor rails, flat-bottom section, 105 lbs. per yard, in 60-ft. lengths.

The various voltages employed in England for traction are 600, 630, 650, 1200 & 1500 V, d. c.: a. c. is used by a few of the English railways. The h. p. of traction motors varies from 120 to 320 h. p. and the weight from 30 to 57 tons. The ratio of h. p. to weight has come down from 57 to 29 in 22 years.

Mention has been made in earlier chapters of the desirability of having model railways in schools and colleges. Where the funds do not permit the purchase of such models from Bassett-Lowke, Meccano, or other manufacturers, slides with descriptive booklets could be obtained from the G. E. C., Metro-Vickers or other firms. One such slide gives otheograph records of steam and electric locomotives, showing the variation of vertical forces on the track, the graphs connecting lbs. and inches, upto 75,000 lbs. and 960 inches for a steam loco. and upto 50,000 lbs. and 540 inches for an elec. loco.

"The weight on the drivers was 248,000 lbs. in the case of the steam loco. (Mikado, 2-8-2) and 309,000 lbs. for the electric loco. Both vertical and lateral impacts upon rails can be recorded. The tests were carried at the Erie works of the G. E. C., N. Y., U. S. A., in Dec. 1923, the speed being 40 m. p. h. (Mr. Mulleneaux, C. E. E., G. I. P. Ry. has designed a track recording car containing a 24 V 100 A generator, two 24 V 320 Ah batteries and an electrically driven compressor with automatic control (air pres. 45-50 lbs.) for discharging whitewash from the underslung tanks for marking the track). In the case of heavy electric locos., it is not possible to replace d. c. motors with single-phase a. c. motors on account of space or drive limitations. Four types of drive used are :— geared axle, geared quill drive, jack-shaft and side-rod, and gearless. Geared axle drive is used in C. M. and St. P. 70-ton shunting loco. having 3,000 V d. c. motors. The Spanish Northern loco. (90 tons) has two 3-axle swivel trucks and six 3000 V d. c. motors geared to the driving axles. The Mexican Ry. has two 12-motor geared loco. (2) Geared quill drive is used with a. c. single phase motors. (3) Side-rod drive is used on the N. Y., New Haven and Hartford R. R., the loco. having four single phase motors, each geared to a jack shaft driving a single pair of driving wheels through side-rods. (The G. I. P. Ry. electric locos. have jack shaft and side-rod drive). (4) Gearless motor drive is used on the Paris-Orleans 6-motor 1500 V loco., and on some 8-motor and 12-motor locos. For the higher speeds common with passenger trains, locos. with 4 trucks are favoured as the effects upon track and flange are minimum." *Descriptive Booklet accompanying Slides.*

APPENDIX I

Symbols.

a—acceleration
A—area, amperes
b—breadth
B.O.T.U.—Board of Trade Unit, kWh.
B.Th.U.—British Thermal Unit (lb.-deg. F.)
c—coefficient of adhesion
,, ,, traction
cu.—cubic
cal.—calorie
°C.—degree Centigrade
c—centi (1/100)
d—distance, diameter
e—efficiency (also η)
f—force
ft.—feet
g—gramme, accel. due to gravity
°F.—degree Fahrenheit
h—hour, height
h.p., H.P.—horse power
in.—inch
k—kilo, 1000
l—length, litre
lb.—pound
m—mile, metre, milli (1/1000)
M—mega (1,000,000)
min—minute
n—number (no.)
%—per cent.; ×—multiplied by

α—temperature coefficient of resistance
η—efficiency
μ—micro, 1/1,000,000
ρ—resistivity
f. p. s.—feet per second
~—cycles per second, alternating current (a. c.)
Ω—ohm
θ—angle
π—circumference / diameter
Ww—weight on driving wheels
W—weight, watts
V—velocity, volts
v—velocity, volume
U—energy or work
T—tractive effort or force
t—time, temperature
yd.—yards
S—speed, space or distance
sq.—square
s—speed, gradient, distance
R—resistance
r—radius, revolutions
sec.—second
p.—per
q—quantity
oz.—ounces
+ plus; − minus

Equivalents, Constants.

1 B. O. T. U. = 1kWh = 3411 B. Th. U. = 2,654,000 ft. - lbs. = 864·5 kg-cal.
1 B. Th. U. = 778 ft. - lbs.
1 gallon = 10 lbs. = 4·547 litres
g = 32·2 f. p. s. p. s. = 22 m. p. h. p. s.
α = temp. coef. of resis. (ohm per deg. C.) = ·00428, copper; ·0038, aluminium
1 H. P. = 746 watts, 550 ft. - lbs. per second, 76·3 kgr-metre per sec.
1 cu. ft., water = 62·35 lbs.; copper, 555 lbs.; iron, 460 lbs.; aluminium., 160 lb.
1 kW = 1·34 H. P., 1 kg. = 2·202 lbs.; 1 kWh = 3411 B. Th. U. (see above)
1 mile = 1·609 kilometre; 1 metre = 3·28 ft.
1 mile per hour = 1·467 ft. per sec. = 0·447 metre per sec.
1 radian = 57·2958 degrees of curvature (angle)
1 ton = 2240 lbs. = 1·017 metric tons = 1017 kilogr. (2000 lbs. U. S. A.)
ρ (specific resis. or resistivity, microhms per in. cube at zero °C.);
for copper—0·625; aluminium—1·05; iron—3·57

Formulae, Facts.

Potential energy, 1 ton at 1 foot = 0·843 watt-hr.

Kinetic energy, 1 ton moving at v m. p. h. = $0{\cdot}0288v^2$ watt-hr.

Work done agt. train resis. of *n* lbs./ton over *d* miles = 1·986 *nd* watt-hr.

Force to produce accel. of 1 m. p. h. p. s. on 1 ton = 102·67 lbs.

Force to move load W up incline $\theta = W \sin \theta$

Resis. at temp. t = Resis. at $0^\circ \times (1 + \alpha t)$

Tractive Effort to overcome Friction or train resistance equals

$$50 / \sqrt{W} + 0{\cdot}03\,v + 0{\cdot}002\,A\,\frac{v^2}{W}\,[\,1 + (n-1)/10\,]$$

where W is weight of train in tons, 2000 lbs.;
v is velocity, miles per hour;
A is cross-sectional area of car above axle (sq. ft.), about 120
n is number of cars in the train.

N. B. $50/\sqrt{W}$ should not be less than 3·5; the side friction of each car increases the friction (air) by 10%.

This tractive effort varies thus; generally speaking:—

for a single car,	10 to 18 lb. / ton	for	25 m. p. h.;	18 to	34	for 50 m. p. h.
„ „ two cars,	7 „ 12	„	„ „ ;	12 „	22 „	„
„ „ three „	5 „ 9	„	„ „ ;	9 „	16 „	„
„ „ five „	5 „ 7	„	„ „ ;	7 „	13 „	„
„ „ nine „	4 „ 5	„	„ „ ;	7 „	„	„
„ „ loco. only	7 „	„	„ „ ;	12 „	„	„

Tractive effort to produce acceleration = Wa/g, if a is in f. p. s. p. s.; or Wa × 1100/12 or 1000 Wa/11 lbs. if a is in m. p. h. p. s. and W is in American tons, as is usual in traction problems.

Tractive effort to supply rotational energy is about 10% of that to overcome train resistance.

Tractive effort to overcome increased rolling friction at curves is 0.78 lb./ton (1 deg curve is one in which a 100′ chord subtends an arc of 1 deg. For grades an additional Tr. Effort of 22·4 (Br.) or 20 lbs. per ton (Am.) for 1°/₀ grade.)

APPENDIX II

Some Links with the Past.

In the Author's previous books on Indian Hydro-electric Installations references were made here and there to railway electrification. As the present book deals with this subject solely, it seems desirable to reproduce relevant paragraphs from those books for the benefit of readers who do not possess them. An appropriate excerpt from *Faraday House Journal*, Oct. '20–June' 22, is also given at the end of this Appendix.

Hydro-Electric Installations of India (H. E. I. I.)

Page 173.—"In connection with the electrification of the Kalka-Simla railway, which is suitable for this conversion on account of the steep gradients on this section of the Himalayas and the remoteness from it of coal-fields, it was expected that 2,000 e. h. p. would be required." This could not be had from the Simla Hydro-electric Installation (described in Chap. XI of H. E. I. I. and Chap. XIV of I. W. P. P.) but could have been furnished by the Sutlej River Project had it been developed for water power and can possibly be supplied by the present Uhl River Undertaking (see I. W. P. P. Chap. XIII) when carried to the second or the third stage of development after the funds are forthcoming on conclusion of the second Great War now being waged between Germany and Great Britain.

Ibid. Page 174.—Regarding the advantages of electric traction, an extract from the London Railway Engineer reproduced by the 'Indian and Eastern Engineer' in March-April 1921 reads as follows:—

"Electric locomotives can deal with steep gradients far more easily than steam locomotives: very much more powerful electric locomotives can be constructed within the limits of permissible weight than steam locos. The Westinghouse locomotives in the New York Tubes can develop 4,000 H. P. with 100 tons adhesive weight......While an electric loco. may cost half as much again as one of the steam type, the difference is admittedly offset by the fact of the infinitely better hauling capacities of the electric locomotive which means that a lesser number would be required to do the work which is accomplished by steam. The great hope for the electrification of Indian railways is the use of water power at small cost for generating the current."

Ibid. Page 34.—In order to utilise the electric power produced by harnessing the Jhelum River at Mohora, it was proposed to put up large industrial plants for the manufacture of chemicals and fertilisers like calcium nitrate (for which lime exists near the river banks and nitrogen could be electrically extracted from the air) or to build an electric railway to a distance of 156 miles (a considerable portion of which would be in hilly tracts). This railway project forms the subject of Chapter VIII of this book. Another suggestion put forward was that for the erection of an aerial ropeway.

Indian Water Power Plants (I. W. P. P.)

Page 45.—An illustration on this page shows an electric-motor-driven rail-trolley used at Sivasamudram to convey men and material from the Bluff to the Water Power Station on the Cauvery River. On the same page, reference is made to the possibility of utilising the Jhelum Power Installation (which could be enlarged considerably as there is no dearth of water) to provide power for an electric railway in Kashmir.

Page 40 contains a reference to the scheme for an electric railway between Bangalore and Mysore which was considered about the year 1930 but has not yet been carried out.

Page 93 contains a reference to the idea of electric trains running between Igatpuri and Bhusaval if the G. I. P. Ry. undertake the electrification of this section in continuation of their existing electric train service from Bombay to Igatpuri. This extension of main line electrification is not likely to present any technical difficulties as the Kalyan Power Station can even now provide the electrical energy required in co-operation with the Bhusaval power station; and the hydro-electric installations contemplated in connection with the Bhandardara Dam and the Pench River may also materialise by the time that the extension is considered justifiable from the commercial point of view.

From the *Faraday House Journal* received in Dec. 1939, it is learnt that in vol. 9 of this journal Sir John Snell anticipated a rapid extension of the electrification of railways as soon as the financial position of the country had improved. The increase of the population, the growing demand for better transport, and the increasing cost of steam locomotion made the electrification of railways a certainty. When the railways were electrified, an additional advantage would be that the cables laid (and lines put up) for them could give supplies of current to many districts which at present have no electric supply.' If this is true of England, how much more so is it of India. If the above mentioned anticipation was fulfilled after the first German War, it is bound to prove true after the second Big German conflict, particularly in the backward parts of India.

APPENDIX No. III

DIESEL-ELECTRIC AND STEAM-ELECTRIC LOCOMOTIVES.

On the Union Pacific Railroad diesel-electric and steam-electric locomotives are employed, of which the following particulars have been gleaned (with thanks) from 'Electrical Engineering' for Oct. 1939 :—

The latest *diesel-electric* train consist of 17 cars. It is propelled by a 3-unit 5,400-h. p. locomotive. With the use of the diesel -electric loco., it is possible to use one loco. all the way from Chicago to the Pacific coast instead of 5 or 6 as was the practice with steam locos. Further, it is possible to increase the fueling and watering points distance to about 500 miles, the stops for this purpose being reduced to 5 from the previous figure of about 25.

2, The Union Pacific 2-unit 5,000-h. p. *steam-electric* locomotive is designed to haul a train of 1,000 tons (trailing) from Chicago, Ill. to the Pacific coast by operating the 2 units in multiple or half the weight by using each unit separately. The steam plant is a closed condensing system containing less than 3,000 lbs. of water. Each 2,500-h. p. unit carries only 4,000 gallons of raw water, only 1/20 of that carried by a comparable sid-rod steam locomotive. Runs of 500 to 700 miles may be made without stopping for either fuel or water. The essential parts of each unit are as follows :—

1. A high-pressure oil-burning boiler, pressure 1500 lbs.. 920° F.

2. A turbine-driven auxiliary set to supply feed-water, combustion-air and fuel-oil to the boiler.

3. Complete automatic control for supplying adequate steam as demanded.

4. A main geared d-c turbine-generating set for traction power (2,500-h. p., $\frac{12,500}{1,200}$ r/m generator (2 armatures back-to-back) 1,320V, 1,300 A ; 3,200 A, 520 V ; max. gen. voltage-1400 V ; excited by a 'metadyne' or variable-voltage exciter.

5. An a-c generator on same shaft for train air conditioning, traction motor blowers and other accessories.

6. Air-cooled condensers for returning steam to boilers as water.

7. Six axle-hung traction motors geared to main drivers, 500-h. p. each.

8. Main control system for automatic and manual control of motor combinations during acceleration.

9. Braking-control system which automatically or manually blends electric braking with air braking.

10. Electric couplers and accessories which permit operation of the loco units singly or in parallel during acceleration or braking.

11. Three separate train-control signal systems to conform to the requirements of the different lines over which the loco. will operate.

TABLE No. 15

Steam-Electric Locomotive Particulars.

a.	Wheel arrangement	-2—C—C—2.
b.	Total weight with tanks full of water and fuel	548,009 lbs.
c.	Weight on driving wheels	354,000 lbs.
d.	Fuel-oil capacity	3,000 gallons
e.	Water capacity	4,000 gallons
f.	Total length over couplers	90 ft. 10 in.
g.	Maximum height above rail	15 ft. ¾ in.
h.	Maximum rigid wheel base	13 ft. 4 in,
i.	Overall width (including grab handles)	10 ft. 8¾ in.
j.	Weight of each traction motor (less gearing)	10,500 lbs.
k.	Traction motor gear ratio	2·097/1
l.	Starting tractive effort	86,500 lbs.
m.	Continuous tractive effort-24 miles per hour	32,000 lbs.
n.	Continuous tractive effort-60 miles per hour	13,050 lbs.
o.	Continuous tractive effort-100 miles per hour	7,520 lbs.
p.	Maximum braking effort	35,000
q.	Maximum permissible speed, miles per hour	125
r.	Braking resister, power absorption capacity	3,600 kW.

APPENDIX No. IV

1. METADYNE. 2. MUTATOR.

A reference has been made in this book to the *metadyne*, regarding which the Journal of Institution of Electrical Engineers for September 1939 gives useful information from which the following has been gleaned :—

"The metadyne is a revolving armature dynamo with a commutator in which, besides the main brushes, additional brushes between the former are placed on the commutator and the main poles are split, and in the spaces, extra poles are put to improve the commutation of the current. Like the Rosenberg Dynamo (largely used for train-lighting of steam trains, in conjunction with secondary batteries), the metadyne is well adapted for constant-current work and has more pairs of poles than ordinary dynamos. It is also suitable for traction because the current can be controlled conveniently, in accordance with the counter–e. m. f. of the motor, the latter depending upon the speed; but even in case of a short-circuit the current will not exceed a predetermined limit. The variation of voltage is obtained by exciter and regulator dynamo. Low speed is made possible without strengthening the field or using rheostats. Likewise for braking' rheostats need not be used owing to the property of regeneration possessed by the metadyne, by which large and steady (not sudden) accelerations and retardations can be produced quickly. The London Passenger Transport Board first experimented with a 6–car train; then ordered 58 metadyne units–(73 more, rays *Times Trade and Engineering*, January 1939).

The Paris-Orleans–Midi Ry. has shunting locos. worked by metadynes, of which the maximum secondary voltage is 1100 V, the continuous rating being 105 kW (870V, 120 A at 995 r/m) and the weight with the regulator dynamo is 6.25 tons. The shunting loco. weighs 53.5 tons compared with 72 tons, the weight of a similar B+B standard loco; the former takes 62.0 Wh. compared with 98.5 Wh, for hump shunting service, taken by the latter; for ordinary shunting service, the metadyne loco. takes 21 Wh. whereas the B+B loco. takes 30 Wh., per ton shunted. The former can exert a tractive effort of 16 tons at the rail and a braking effort of 11 tons. Regenerative braking is for regular use but air braking is provided to comply with the regulations and for emergency use.

The Journal of Inst. Loco. Engineers, Sept.—Oct. 1939 gives the following information and statistics :—"London Transport Board—electrified lines metadyne control motor cars (H & C) Saloon 114, 152 h. p,; trailers, 76. Metadyne stock is designed for 8–car formation and can be worked as 2-, 3-, 6- or 8-car trains. The metadyne unit takes a supply at line voltage and gives out to the motors a supply current which during the acceleration period is automatically varied so as smoothly to increase the acceleration to a maximum and subsesuently reduce it to give a balancing effect. The voltage applied to the motors bses to rather more than the full line potential as the motors come up to speed. The unit consists of one large machine and two small machines coupled under the coaches,

The *metadyne* system is specially suited for suburban traction, as rheostatic braking which is admittedly wasteful can be replaced by regenerative braking. On main lines, the latter form of braking can be employed even with ordinary locomotives and metadyne control is not calculated to contribute to enhanced economy or efficiency of operation.

2. The October 1939 number of the I. E. E. Journal contains a Paper on 'Frequency-changing with mercury-arc *mutators*' by Dr. Feinberg, University of Manchester (formerly with the A. E. G. Research Laboratories, Berlin), which is of interest to railway engineers, as pointed out on page 69 when considering singlephase systems for traction. The employment of low frequencies for traction creates a demand for frequency changing, which is met by mutator converters. Frequency changing may be achieved either with a direct coupling mutator converter or with such a converter with intermediate direct voltage. Usually 3-phase 50 cycle supply is changed to single-phase 16-2/3 cycle supply.

APPENDIX No. V

INDIAN WATER POWER PROJECTS AND CORRELATED RAILWAYS.

Of the Indian railways which have been electrified up to the present date, the G. I. P. and the B. B. & C. I. Railways and the B. E. S. & T. tramways use water-produced electrical energy for running their suburban trains and Bombay tramcars respectively; the power being sent to Bombay for this purpose from the Tata Hydro-electric stations at the foot of the Western or the Bhore Ghat. The G. I. P. Railway which takes the pride of place as the only Indian railway employing electric power for main-line traction does not use water-generated electricity for this purpose but uses coal imported from the Central Provinces. Likewise, the S. I. Railway relies upon current produced by imported fuel for operating its electric trains, the fuel being imported by the Madras Electric Power House which supplies the current.

The electrification of the following railways could be carried out with the help of electric power from the hydro-electric stations and systems mentioned alongside of them which can supply the required power :—

TABLE No. 16

Indian Hydro-electric Systems and Correlated Railways.

Hydro-electric System (River)	Railway
Pykara	Nilgiri*
Mettur Dam	Madras suburban section
Cauvery	Mysore-Bangalore
Jog or Gersoppa Falls, Sharawati	Shimoga section, Mysore Railways.
Uhl	Kalka-Simla
Uhl	Kangra section of N. W. R.
Uhl	Lahore-Amritsar
Uhl or Upper Ganges Grid	Delhi suburban Section
Jhelum	Proposed Railway for Srinagar.

* Please see note under Table No. 17.

The electrification of the following railways could be carried out from the corresponding proposed water-power projects, if ever the latter are taken in hand:—

TABLE No. 17

Indian Water-Power Projects and Correlated Railways.

Water-power Project	Railway to be electrified.
Karjan R., Rajpipla State	Ankleshwar-Nandod
Panam R., Lunavada State	Godhra-Lunavada
Koyna R., South Maharashtra	Western Ghat section of M.& S. M. Ry.
Sutlej R., the Punjab	Kalka-Simla Ry.
Jhelum R. or Chenab R. (Rasul or Riasi)	Sialkot-Jammu (N. W. R.)

* A project to develop the Coonoor and Karteri River near Runnymede Station to give about 1000 K. W. from a head of about 1000 ft. for the electrification of the Nilgiri Ry. was drawn up by Mr. J. W. Meares in 1905 as stated in T. R. W. P. R. which also refers to the Hukong valley Nongyoung River Scheme of Assam and the possibility of the Burma-Assam Ry. passing by the site of the power station but the unlikelihood of this railway being worked electrically owing to the propinquity of coal and the paucity of traffic. The possibility of electrifying some of the railways in the Punjab adds to the interest of the Uhl R. Scheme, according to the Indian *Year Book* 1939-40, which refers only to the G. I. P. Ry. main line (Kalyan to Poona) in a short paragraph headed Electrification, though it has a big section on 'Railways'.

APPENDIX No. VI.

CONTRASTS BETWEEN INDIA'S ELECTRIC RAILWAY TRIO.

There are only 3 different railways in India which employ the contact method for collecting the current required for running their trains by contacting the pantograph collectors with the overhead conductors. Other contact methods e. g. third-rail method are not used anywhere in India. The trio of India's electric railways comprises the G. I. P. and B. B. & C. I. Railways terminating at Bombay and the S. I. Railway terminating at Madras. Only one of these, viz. the G. I. P. Ry. has electrified the Ghat sections of its main lines to the South-east and North-east. The main-line overhead equipment of the G. I. P. Ry. is more elaborate and substantial than that for the suburban sections of either this or the other Bombay railway, in several particulars. The overhead equipment of the B. B. & C. I. Ry. (which is identical with that of the G. I. P. Ry. suburban section) is stronger than that of the S. I. Ry. The reasons for these disparities will become understandable after a study of the subjoined Table No. 18. On the other hand, the S. I. Ry. is the only one employing rectifiers in steel tanks. This railway has, moreover, battery tenders with locomotives and the B. B. & C. I. Ry. has two 228-h. p. shunting locos. and two battery locomotives. The G. I. P. Ry. has a large number of locomotives but none specially meant for shunting, or making up, of trains.

Table No. 18.

Contrasts between India's Trio of Electric Railways.

ITEM	G. I. P. Ry.	B. B. & C. I. Ry.	S. I. Ry.
Mileage-route, track	Suburban-43, 69 Main Line-138, 338	1st. instt. 22½, 57 2nd. „ 37, 91·58	18½, 46 Train miles 3,026 per day
D. C. Overhead conductors: suburban „ main line	Catenary-0·375 sq. in Contact —0·25 Catenary -0·5 (main catenary wire) „ -0·2 (auxiliary catenary) Contact —0·3 sq. in.	0·375 sq. in. 0·25 „	0·25 sq. in. 0.2 „ Railweight— 75 lbs. per yd.
Traction Substations	Suburban-4. „ kW-17,500 Main Line-11, 65,000 kW.	1st. instt.-3. „ „ 20,000 kW 2nd. instt. 1, „ 4,000 kW.	2 3,000 kW ton-miles (gross) 237,860 per day
Locomotives	Goods-41;2600 hp. Passenger-25; 2550 h. p each.	Battery-2;55 ton each Shunting-2;228 h. p.	Battery-4; 320 h. p. each
Maximum demand, kW.	20,000	7,670	1,500
Energy consumed, yearly	50·3 million	30·6 million units.	14,500 daily
Passengers carried	27 million, 1928	38 million, 1928	9 million, 1937
Trains, daily; Gauge	; broad 5′ 6″	40 : 66″, broad	145 ; metre
Conversion of a. c. to. d. c.	Synchronous or Rotary Converters.	Rotaries. Rectifiers.	Rectifiers
Locos. for shunting etc.	Ordinary.	Battery	Battery

* Rectifiers, being like valves in their behaviour, do not permit current to pass from the line to the source of supply and the line pressure may rise to abnormal values whenever there is excess of regenerated energy ; to obviate this risk, a loading resistance should be automatically connected, by being made responsive to rise of bus bar pressure by means of contactors. On the G. I. P. Ry., regeneration occurs on the Ghat section and rectifiers are not used ; a loading resistance is provided outside Karjat substation. Fig. No. 31 shows a rectifier and a motor-generator set at Kingsway substation for traction supply of the Bombay Electric Supply and Tramways Company, the photograph having been kindly supplied by Mr. A. S. Trollip. Fig. 31 appears on page 88.

APPENDIX VII

ELECTRIC TRACTION TERMINOLOGY—GENERAL DEFINITIONS

Acceleration—Rate of change of velocity with respect to time.

Adhesive coefficient—see Coefficient of adhesion.

Adhesion, coefficient— „ „

Air brake—a brake operated by air, usually from a compressor.

Arc rectifier—see Mercury Arc Rectifier.

Blow-out magnet—a magnet which produces a field at right angles to an arc to extinguish the latter.

Bogie—a low truck on a revolving frame, usually double i.e. two trucks joined together; 2 or more axles in common side-frames joined by a bolster or cross piece carrying a centre plate, the car-body resting on side-bearing plates.

Bolster—see Bogie.

Bond—a short copper conductor joining rails at a joint.

Booster—a motor-generator used for boosting i.e. providing an additional voltage; a *negative booster* is connected in the negative feeder to reduce the drop in volts,

Bow collector—a metal bow-shaped collector of current from an overhead wire.

Brace, pole—see Pole Brace.

Bracket—a rigid arm fixed to a pole and carrying an insulator to which a wire or cable carrying current is firmly tied, or carrying a catenary or messenger from which the contact wire is suspended

Braking, dynamic—see below, Dynamic braking.

Braking Effort—see Retarding Effort.

Bridge system—Brackets at both sides of the track or tracks, fixed to each support or pole.

Buffer—an apparatus for deadening a blow (when a train come to a halt).

Cam control—control effected by a cam shaft, operated by compressed air, moving a number of contactors.

Cascade—see Concatenation.

Catenary—curve assumed by a freely suspended chain (catena) or wire rope; the latter being called messenger and supporting the collector or contact wire by droppers.

Characteristic—a line (usually a curve) showing the variation of one quantity with respect to the variation of another, on a graph sheet (vertical distance, ordinate and horizontal distance, abscissa); ordinarily used in study of dynamos, including motors.

Closed Conduit—see Surface contact.

Coasting—moving under the action of gravity or momentum, without requiring expenditure of fresh energy; this being no more supplied.

Coefficient of adhesion—the ratio between total tractive effort and weight on driving wheels.

Collector—see Catenary.

Compound catenary—system having more than one catenary or messenger wire.

Concatenation—connection of the stator or rotor of an induction motor to the rotor of another (also called cascade).

Condenser—an appliance for storing electric charge or capacity.

Conductance—the reciprocal of resistance.

Conduit—a groove or passage under the track for the conductors of a tramway or railway system.

Contact rail—a rigid conductor with which contact is made in order to convey current to the motors.

Contact, surface—see Surface contact.

Contactor—a switch operated by solenoid, receiving current from another source* and moving the finger carrying the movable contact.

Controller—switch or switches for starting, or controlling the speed of, traction motors. The master controller has two handles, one for the forward, the other for the reverse, direction of the train (located in vestibule at either end of the car).

Control, multiple-unit—system or method for moving simultaneously controllers on all the cars or motor coaches (one such system is the Sprague system); cars being coupled in any combination.

Converter—a machine for converting a. c. to d. c.

Coupler—cable for coupling electrical circuits of cars by plugs, and sockets, so designed as to make it impossible to insert the plug in the socket improperly.

Cross-span wire—a flexible wire across the track or tracks, from which the conducting wires are suspended; more than one flexible wire is used in the messenger cross-span supporting system.

Deadman's switch or button—button or switch on the operating handle of master controllor, usually kept down (except in off position) by pressure of operator's handle ; if this is released by operator becoming disabled, an auxiliary circuit is opened, cutting off the supply to the contactor.

Deceleration—Retardation or braking.

Direct Suspension—overhead trolley wires attached by insulating pieces directly to main supporting system.

Drivers—driving wheels of traction car or locomotive.

Droppers—short wires by means of which the collector wire is suspended from the messenger or catenary cable.

Double truck—see Bogie.

Dynamic braking—braking by working a motor as a generator, taking no current from the line except that required for excitation.

Dynamometer—(1) instrument for measuring forces delivered by machines (e. g. force required for moving a train); (2) instrument indicating amps., volts or watts by action of current in fixed coils upon current in moving coil.

---

* (train wires from a master controller).

Ear—clamp soldered or attached to trolley wire.

Effort, tractive—see Tractive Effort.

Engineer—engine driver.

Feeder—cable from power station or system, feeding supply to distributor at a distant point, no current being tapped off *en route*.

Field Control—Controlling the speed of a motor by altering the strength of the field circuit.

Filter circuit—network of R, L, and C (or 2 of these), passes through signal of some frequencies better than others.

Frog—overhead point in trolley wire at certain places where single track is laid with rail switches at intervals for passing cars ; avoided by using double trolley wires.

Fourth rail—a rail between the two running rails on the same sleepers, cross-bonded to them and bonded at its joints, to supplement the conductance of the running rails.

Grade —see Gradient. Equivalent Grade—see Gradient, Virtual.

Gradient—ratio of distance raised to distance travelled i. e. of altitude or ordinate to hypotenuse of right-angled triangle.

Gradient, Ruling—Maximum gradient met with on any section of the track.

Gradient, Virtual—a little less than the real gradient, on a limited length of the track—the train ascends the grade because of the fly wheel effect combining with the tractive effort (also called Equivalent Grade).

Guy—wire used to keep pole upright at angles, terminals or slopes.

Hanger—bronze casting for hanging the trolley wire ; supporting but insulated from a steel bolt ; attached to span-wires (the bolt is attached to the trolley wire by the 'ear').

Hanover system—system in which only outlying parts are equipped with overhead wire, central portions being without it and being covered by a battery on the car or on a tender hooked on to the car.

Harmonic suppressor—device for suppressing harmonics to prevent interference with telegraph and telephone circuits.

Headway—time between consecutive cars or trains.

High-tension chamber—chamber in a motor coach or locomotive in which equipment connected to supply mains carrying a high tension or voltage (say, 1,500 V or more) is mounted.

Hospital Switches—switches in a controller for cutting out either motor if it breaks down and allowing the car to be driven by the other motor.

Impulse—small sudden force or wave or change in current.

Ignitron—a mercury arc rectifier in which the arc is started by a special igniter, not requiring any moving parts.

Induction generator—induction motor (running light and still connected to supply circuit) run above synchronous speed acts as a generator, provided supply is from a station containing a synchronous generator.

Induction Regulator—transformer whose voltage ratio can be adjusted.

Inductor—appliance possessing inductance.

Interlocks—assemblage of switches etc. and signals so inter-connected that their movements must follow one another in proper sequence, thus safeguarding against wrong operation.

Inverted Rotary—a rotary converter used to change d. c. to a. c.

Jumper—short connector of stranded copper wire or cable.

Key—switch.

Lead—main wire from positive (or negative) side of supply system.

Lightning Arrester—device for arresting lightning or surges of abnormal electric pressure, thus protecting apparatus and circuits.

Locomotive—engine for moving train from place to place.

Magnetic brake—brake acting due to eddy currents induced in metallic disc rotated between poles of a magnet.

Magnetic Track brake—track shoe drawn by powerful electromagnet against the rail, thus acting as a brake.

Mast—light upright pole.

Master controller—see Controller, master. It has 3 points, the first gives the first series position, the second all series position and the third all parallel position.

Maximum traction truck—truck for traction in city streets at speeds not exceeding a maximum (say 30 m. p. h.).

Mercury arc rectifier—static device utilising the arc of mercury as a cathode, for rectifying a. c. to d. c.

Messenger—wire or cable running along and supporting the collecting (or contact) wires or cables.

Messenger, primary—messenger directly attached to the support.

Messenger, secondary—messenger intermediate between primary messenger and contact conductor.

Metadyne—see Appendix IV.

Monophase—see single phase.

Motorman—driver of train of motor coaches.

Multiple unit system—see Control, multiple unit.

Mutator—see Appendix IV.

Negative Booster—see Booster.

Notching Relay—relay which in connection with notching lever of master controller provides step-by-step notching on heavy grade etc. where current required by motor exceeds that for which the limit relay is set.

Open Conduit—open or slotted channel between the rails or under one rail, in which contacts attached to conducting pieces are placed.

Otheograph—graph showing variation of vertical forces on track.

Pantograph—device for collecting large currents from overhead wires; sometimes written as pantagraph (instrument by which reduced or enlarged copies of designs or drawings may be made (pan-all; graph-write).

Period—time required by a. c. to complete one cycle.

Permanent way—complete track of a railway or tramway.

Phase—fraction of period since current passed through zero position.

Pilot motors—electric motors with 2 oppositely-wound field windings driving controller barrel through worm gearing.

Pilot valve—a valve on master controller for emergency brake gear.

Pinion—small wheel with teeth fitting into those of a larger one.

Plough—device under a tramcar carrying 2 cast-iron shoes making contact with conductors in a conduit.

Points—the place where one set of railway etc. joins another.

Pole Brace—short pole used to brace or strengthen the main pole.

Polyphase—having more than one phase of alternating currents coming from the same source but reaching their respective crest or maximum values at different times.

Power House—see Power Station.

Power Station—building where power-generating plant with its accessories is installed.

Primary Messenger—see Messenger, Primary.

Pull-off—a piece with one or two side arms insulated on a mast or support attached to the contact and catenary conductors to pull them sideways and keep them over the centre of the track e. g. at curves.

Railcar—car or tram driven by oil engine on rails.

Railmotor—motor car run on rails.

Railroad—railway.

Reactor—appliance possessing reactance.

Receiving Station—building where power is received from a Power Station to be forwarded on to substations.

Rectifier—appliance for rectifying a. c. to d. c.

Regeneration—operation of a motor as a generator.

Regenerative braking—see Dynamic Braking.

Register-arm—arm attached to a cross-span wire to restrain the contact conductor from being blown away by the wind.

Relay—instrument, moving finger moved by impulses of current from distant source, to open or close local circuit.

Resistance, Train—resistance due to frictions tending to retard the motion of a train, expressed in pounds per ton.

Resistor—device having resistance of a fixed value.

Retarding Effort—force tending to retard the motion of a train and bring it to rest, expressed in lbs.

Return—main wire or cable for returning the current to the negative side of supply system (usually the rail).

Reverser—switch having as its movable part a rocker arm operated by 2 electromagnets working in opposition, used to run motor in 'reverse' direction.

Reversing Drum—drum having fixed fingers and rotatable contacts, used to reverse direction of rotation of traction motor by changing connections between armature and field windings.

Rheostat—apparatus possessing resistance with means for changing the amount of resistance introduced in a circuit.

Rotary Converter—rotary machine for converting a. c. to d. c., having a single armature with commutator at one end and collecting rings at the other end.

Ruling Grade—see Gradient, Ruling.

Run-back preventer—braking action of motors used to prevent the car from running back after having stopped on a hill (motors are short-circuited by means of the controller and act as generators owing to reversal of rotation).

Schedule Speed—average speed of train, taking all stops, slowdowns etc., into account; distance run divided by time elapsed.

Selector—device like relay or switch which selects a particular impulse, signal or current of a certain frequency.

Semaphore—pivoted arm with coloured glasses for signalling.

Series-parallel connection—controlling speed of motors by connecting them first in series and then in parallel.

Shunting—turning a train from one line to another or to a siding.

Simple Catenary—system having a single messenger or catenary wire.

Single phase—alternating currents from a single coil, having a single phase or set of cycles.

Skate—device for collecting current from contact studs or wires.

Slot rails—rails fixed slightly apart from each other to form the slot of a conduit system.

Span wire—wire fixed to supports on either side of a track across the current-carrying overhead conductors.

Spark shield—shield for extinguishing the spark occurring when connections are altered in a controller.

Strut—timber (or pole) set obliquely to strengthen the main pole or support, cf. Brace.

Substation—building where power from a generating or receiving station is distributed through switchgear and machinery to current-consuming appliances.

Subway—underground passage, 'Tube'.

Sucking transformer—transformer reducing the voltage-drop in a rail, cf. Negative Booster.

Surface Contact system—system employing fixed contacts or studs, at intervals between the running rails, over the surface of which slides a 'skate' beneath the car to make contact; studs are made 'alive' while the car is over them and 'dead' when it has passed.

Switch—movable rail for passing a train on to another line; contrivance for making or breaking a circuit.

Switching—shunting, see above.

Swivel—fastening enabling a truck or a trolley head to move on an axis.

Synchronous condenser—synchronous motor operated so as to act as a condenser, producing a leading current and improving the power factor of the system.

Synchronous converter—see Rotary converter.

Tap potential control—control by connecting motor terminals successively to transformer taps of increasing potential, while starting a motor.

Third rail—insulated contact rail conductor placed at the side of the track, the contact surface being a few inches above the level of the running rails.

Torque—turning moment; force multiplied by radius.

Three phase—alternating currents of 3 phases, currents reaching same maximum value but at intervals of one third of a 'period'.

Throttle magnet—magnet which breaks the pilot motor circuit if current in main motor exceeds a certain value.

Thyratron—rectifier with one or more control grids or electrodes.

Track curve—1 deg. curve is one in which a 100' chord subtends an angle of 1 degree at the centre.

Trackless trolley—see Trolley-bus.

Traction coefficient—tractive force divided by weight of loaded car.

Tractive Effort—force required to draw a train.

Trailer—car without motors, intended for carrying passengers only.

Train performance curves—curves showing variation of current, speed and distance against time.

Train resistance—force tending to retard motion of train (lbs./ton).

Train wires—wires from controller to contactors or circuit breakers for closing the latter in proper sequence.

Tramcar—car which runs on a tramway ; also called Trolley car.

Tramway—track made of trams i. e. beams, plates or rails, over which cars are drawn in city streets ; also called Street Railway.

Trolley—small narrow cart or truck with small wheels; small bronze wheel contacting with grooved copper conductor over centre of track of tramway or street railway.

Trolley arm—thin tapered steel tube enclosing cable making contact with trolley wheel.

Trolley bus—omnibus run by current from 2 overhead conductors on ordinary (railless) roads.

Trolley car—see Tramcar.

Trolley pole—see Trolley arm.

Trolley roller—used in place of trolley wheel where it is desired to use reversible collecting construction or where potential is so high that all control of collecting devices should be automatic (not manual).

Trolley wheel—small wheel at top of trolley arm, wheel head being mounted on hard sleeve to prevent current leaking to pole and standard.

Trolley wire—flexible contact conductor customarily supported above the cars.

Truck, Single—single-truck car used for service in city streets where maximum speed should not exceed 25 m. p. h. : the two axles are rigidly aligned by side-frames.

Truck, Double—see Bogie.

Tube—see Sub-way.

Underground railway—railway in a Subway or Tube.

Vacuum exhauster—machine for exhausting air and producing vacuum.

Vacuum brake—brake acting by forming a vacuum in cylinders under each carriage of a train.

Virtual grade—see Gradient, virtual.

Books consulted:—Standard Handbook for Electrical Engineers, Whittaker's Electrical Engineer's Pocketbook, Maccall's text books on Electrical Engineering.

(Readers will please intimate any errors of omission or commission, citing the exact authority for the correction, alteration or addition).

N. B.—Definitions of ordinary hydraulic and electrical terms may be seen in '*Hydro-electric Stations in India,*' by the Author of this book.

APPENDIX VIII

ELECTRIC TRACTION CHRONOLOGY

Important dates in the history of electric traction, particularly dates on which electric traction was introduced in some form or other, have been given below.

Table No. 19

YEARS OF COMMENCEMENT OF ELECTRIC TRACTION

Event		Year
First electric railway loco. (steam-electric) shown at Berlin Exhibition	...	1879
,, ,, ,, , third-rail, opened in Berlin	...	1881
,, ,, ,, , steam-electric, ,, ,, Ireland	...	1883
,, ,, ,, , gas-electric, ,, ,, Brighton	...	,,
,, ,, trolley-car appeared in U. S. A.	...	,,
,, ,, loco. standard gauge ,, ,, ,,	...	,,
,, ,, elevated railway ,, ,, ,,	...	1885
,, ,, underground ,, ,, ,, ,,	...	1889
,, ,, ,, ,, ,, ,, London	...	1890
,, ,, Overhead ,, ,, ,, Liverpool	...	1893
,, ,, suburban ry. U. S. A., and tramway in Madras	...	1895
,, ,, section of Waterloo & City railway	...	1898
,, ,, three-phase alternating cur. ,, Switzerland	...	1899
,, ,, section of Central London railway & in France	...	1900
,, ,, loco. tests, U. S. A.; and railway in Italy	...	,,
,, ,, trolley-bus in Dresden	...	1901
,, ,, train on Mersey Tunnel railway	...	1903
,, ,, ,, ,, Lancashire and Yorkshire railway	...	1904
,, ,, subway test, U. S. A.	...	1905
,, ,, tramway in Bombay	...	,,
,, ,, ,, ,, Delhi	...	1908
,, ,, vehicle ,, U. S. A.	...	1910
,, ,, train, Stockholm—Saltsjon, and Riksgrans Ry.	...	1913
,, ,, railway ,, India, Harbour Branch, G. I. P. Ry.	...	1925
,, ,, ,, connection between B. B. & C. I. and ,,	...	1926
,, ,, ,, suburban section, G. I. P. Ry.	...	1926
,, ,, ,, ,, ,, B. B. & C. I. Ry.	...	1928
,, ,, Main-line ,, G. I. P. Ry.	...	1929
,, ,, Suburban ,, S. I. Ry.	...	1931
,, ,, diesel-electric railcars G. B. S. Ry.; and C. P. Ry., worked by G. I. P. Ry.	...	1932
,, ,, trolley bus in India, Delhi E. S. &. T. Co. Ltd.	...	1934
,, ,, main-line railway in England	...	1939

No. of units in Great Britain for railway traction-1353 million	...	1937
,, ,, ,, ,, India ,, ,, ,, 151½ million kWh.	...	1938

N. B.—Other statistics may be seen in Chapter XII.

INDEX.

APPENDIX IX — Final Additions.

Chap. XII-A. The Indian Railway Budget for 1940-41 provided for a surplus of Rs. 829 lakhs. In the revised estimates for 1939-40, a surplus of Rs. 361 lakhs was expected, and for the State-owned lines, the revised estimates for gross earnings and working expenses were Rs. 97.30 crores and Rs. 65·35 crores respectively.

" *Chap.* XII-B. (i) Manchester-Sheffield electrification. L. N. E. Ry. ordered 8 locos., each 102 tons and equipped with 6 motors, 345 h. p. each (1500 V d-c). (ii) First stage of electrification of Central Ry., Brazil has been completed. *Chap.* VII. London Transport are experimenting with a B. T. H. diesel-electric loco. *Chap.* X. (*a*) During the year, 39 route miles of tramway were converted to trolley bus operation, bringing the total mileage converted to 191 miles." *Times Trade and Engineering, Jan. 1940.*

Chap. X. Electric vehicles consume 90 to 120 Wh. per gross ton-mile.

TABLE NO. 6 (*a*) —ELECTRIC BATTERY VEHICLES.

Battery kWh. ...	12—15	20—24	25—30	30—36
Avg. Speed, m. p. h. ...	12—14	9—11	8—10	6·5—8
„ Mileage, daily ...	45—50	35—40	30—35	25—30
„ Weight of vehicle, tons	2	3·5	4·5	6
„ „ „ battery „ ...	1	2	3·5	5

(Rentell's Electrical Pocket-Book).

Chap. VII. Diesel Electric or Mechanical Railcars and petrol or oil railmotors could probably be introduced on certain sections of railway branches and of Light Railways e. g. that of Gwalior, Barsi, Rajputana, Kathiawar, etc.

" Indian Water Power Plants "

BY

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Printed at the Aryabhushan Press; 1937. Cloth, $6\frac{1}{2} \times 10$ in. 180 pages.

Twenty chapters, 6 appendices, 38 Tables, 36 illustrations, Rupees Five.

A companion volume to the same author's book entitled " *Hydro-Electric Installations of India* " ; 1922. 310 pages. Rs. 7–8–0.

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1. **Indian Engineering,** Calcutta.

"......a *work of absorbing interest*......the history and growth of water-power plants and projects of India is traced step by step......" (The last but one chapter deals with the Water-Power Projects of Burma).

2. **The Times of India,** Bombay.

" This book presents in popular form some important facts relating to the hydro-electric development in India. The introductory chapter is rightly designed to establish close connection between Water and Electricity and their collaboration in the service of Man. The history and growth of hydro-electric projects in this country is traced gradually and fair comparison is drawn between the different systems and schemes. One chapter has been devoted to the discussion of water power development in other countries and their achievements. Subsequent chapters deal with the progress and present position of Indian hydro-electric plants in different provinces and States.

This book is *indispensable to both engineers and technical students* who desire to have an up-to-date knowledge of the subject. It is *written in simple and readable style and the illustrations* are both *numerous and well-executed.*"

3. **Indian and Eastern Engineer,** Calcutta.

" *Indian Water Power Plants* follows *Hydro-electric Installations of India* by the same Author and supplements it in natural sequence. A brief history of most of the major water power plants in India precedes a general resume of progressive tendencies abroad and then the author deals in detail with all the various installations, one by

one. There is *no unnecessary filling* and the figures pertaining to each scheme have been *recorded in such a straightforward manner* that cross references and comparisons are very quickly made.

Probably *the most matter per page of any book yet reviewed* in these columns."

4. **Indian Textile Journal**, Bombay.

"......The twenty chapters, six appendices, three dozen tables and three dozen illustrations go to make it *a valuable reference book* of *great interest to all engineers*......Impressive as has been the development of hydro-electric power in certain areas, there is still very great room for expansion......"

5. **Electrician**, London.

"......The author who is Professor of Physics and Electrical Engineering......supplements and brings up to date the information contained in his *earlier work which was very well received*.......The book presents a *useful historical section* and gives a *great deal of information* which has hitherto only been available in scattered form. It gives an *excellent idea of the extent* of the development that has taken place in recent years."

6. **Electrical Review**, London.

"...........this volume will be found *useful as a book of reference*."

7. **Distribution of Electricity, London.**

".........It forms a *useful record* of the tremendous progress which has been made in developing the hydraulic resources of India. The sources from which the author has derived his information are *fully indexed*, whilst *numerous illustrations and graphs* accompany the text."

8. **The Faraday House Journal**, London.

"We congratulate the author on having written a *most interesting* book. He is an enthusiast about water power and the writing of this book must have been a labour of love......"

9. **Engineering Society's Journals**, U. S. A.

"Descriptive information concerning hydro-electric plants and projects of the past decade in India and Burma, geographically divided, showing the present position......"

10. **College of Engineering Magazine**, Poona.

"......this *very interesting and instructive compendium* on Indian Water Power Plants. It has supplied a need very keenly felt for a long time by students and industrialists. Happily the book is *replete with such a mass of useful data* that there is no doubt that it would easily command the first place as a book of reference on the library shelves of those interested......Prof. Shiv Narayan has done a real service to the country. The book is strongly recommended to both laymen and professionals as a *very illuminating and inspiring guide*. The figures quoted by him are both *accurate* and *up-to-date*."

11. **Electrotechnics,** Bangalore.

" In the present book, he has managed to compile a *good deal of information scattered* in various reports published by provincial governments. The first four chapters deal with the history and growth of Indian water power plants. The possibility of future developments has also been pointed out. A comparison of hydro-electric schemes in and outside India gives a *good picture of our present position*......includes information about the type and capacity of headworks, turbines and generators. General information about the switchgear and transmission lines is also included."

12. **Col. C. Graham Smith, O.B.E., A.M.I.C.E.**

" Having looked through the manuscript of Prof. Shiv Narayan's new book, I have *no hesitation in recommending*...As far as I am aware, nothing of the sort has been published for a dozen years or so and it is desirable to bring the record up-to-date..."

13. **F. O. J. Roose, M.I.E.E., M.I.M.E., former Electrical Engineer to Government,** Bombay.

" I have gone through Professor Shiv Narayan's manuscript with care and must congratulate him on having produced *a work of great interest to all engineers* who are in any way associated with the production of electricity by use of water power. The author has collected in one volume *an enormous amount of data*...shows very clearly the enormous development...He describes in great detail the different schemes, those whose draw-off is taken from impounded rivers, reservoirs fed by irrigation canals and reservoirs fed from the rainfall run-off from large catchments. He also discusses the transmission line construction......together with their transformer stations...... 'Indian Water Power Plants' is *a valuable book of reference* and I wish it every success and a very wide circulation."

Other books by the same Author, obtainable from—
Messrs. BRIJ NARAYAN & CO.,
1 Ganeshkhind Road, Poona 5, India, are :—

Hydro-electric Stations in India (1940) (Rs. 3–12–0 only).

Containing information not given in (I.W.P.P.), also some important matter which had appeared in H.E.I.I. (1922), now out of stock.

Lightning, Lightning Conductors and Arresters.

(35 pages, 17 illustrations. Re. 1–0–0 only.)

Electric Generators, Motors and Circuits.

(32 pages, 19 illustrations. Re. 1–0–0 only.)

A few of the opinions and reviews about these three books will be found on the following pages.

Book ready for Press :—**Electric Railways in India.**

(Probable time of publication, Dec. 1939 ; price—Rs. 4–8–0)

Next Book :—**Wireless Stations in India.**

OPINIONS ON "HYDRO-ELECTRIC INSTALLATIONS OF INDIA."

Re-issued in 1940 as 'Hydro-electric Stations in India.'

A Treatise for the use of Students, Engineers, Industrialists and others.

Mr. S. Sarkar, B. Sc. (Eng.)—a younger member of the profession not acquainted with the Author writes:—

I have just gone through your excellent handbook 'Hydro-electric Installations of India' and I take this opportunity to convey *to you my heartfelt thanks* for putting before me in a nutshell the hydro-electric position of India.

The difficulty experienced by hydro-electric students in India arises from two factors:—

(1) There is no central department in India which deals with this subject. Since the Montford reforms, this subject has been transferred to the Provinces and as such it has lost much of coherence...

(2) There is no hydro-electric journal in India which can do the same work in absence of a Govt. Dept.

Hydro-electric students have therefore no option than to fall entirely on *such painstaking work of Authors as you are.*

I shall crave your indulgence in this letter if you can kindly give me the following information:—

(1) If you have revised your book since 1922 and brought it up-to-date. (2) If not, will you kindly give me a list of Hydro-electric stations that have come into operation since 1922 and stations under construction.

A brief outline with principal features of stations will be very welcome as it would undoubtedly help me in the pursuit of the study of further details.

N. B.—The new books *Indian Water Power Plants* and '*Hydro-electric Stations in India*' recently published supply the required information.

Sir Sydney Crookshank, Secretary to Government of India, Public Works Dept., Simla.

It is an interesting and instructive production on which I congratulate you. I read it with great interest.

Mr. Venkatarao, Siragala Farm.

I will never repent having paid for the book as all the information about Hydro-Electricity is beautifully epitomised in it. It is a book worth having.

" Industry," Calcutta.

The public owes a deep sense of gratitude to Professor Shiv Narayan for his very timely appearance with a decent manual, even a glance on the contents of which will show it to be undoubtedly a work of authority on the subject.

Late Principal, College of Engineering, Poona,

Mr. Shiv Narayan has written a most readable and instructive book which certainly fills a want in Indian technical literature. As a book of reference, it is of great value, giving as it does useful data regarding existing and proposed Hydro-Electric Schemes in India and the accounts of these works which are given are written in a manner both lucid and interesting. The simple explanations and examples of fundamental theory which are given should be valuable to students and to capitalists desiring to understand broad principles. An excellent book.

" Indian Industries and Power," Bombay.

The book comes very opportune at the present moment and we have no doubt will be well received by all those who are interested in the industrial progress of India generally and in hydro-electrics particularly.

Executive Engineer, Public Works Department and Professor of Civil Engineering.

A very handy volume, giving a bird's eye-view of the development of Hydro-Electric Works up-to-date in India. Of much interest to students as well as to businessmen engaged in this department of engineering......written in an easy, simple and readable style, with information as full as one would wish on each work described.

Director of Agriculture, Bombay Presidency.

Very many thanks indeed......I hope the book will be a very great success.

So also wrote the **Director**, Indian Institute of Science, Bangalore.

Chief Electrical Engineer, Kashmir and Jammu.

Congratulate you upon your articles upon the Jhelum Power Installation and Electric Dredging, etc.

Rao Sahib G. Sundaram of Madras.

I have great praise for you for the time and trouble you have taken regarding this book and your success in condensing into it a really mighty mass of information. I am sure your second book will be as valuable an addition to an engineer's library. I request you to register my name for it.

N. B.—The second book has been published under the title of *Indian Water Power Plants.* The third book (abridged withal up-to-date edition of 'H. E. E. I.') is called '*Hydro-electric Stations in India.*'

An Engineer in France.

Congratulate you on the Volume of Information.

Engineer, Lighting Department, G.E. Co., Schenectady, N.Y., U.S.A.

We are keeping a volume of your book in this Department as a Valuable Record of the Indian Electrical Installations.

"Times of India, Engineering Supplement."

HYDRO-ELECTRICS.

Shiv Narayan's New Book.

The technical literature of India has received a valuable addition in Professor Shiv Narayan's new book, "Hydro-Electric Installations of India."

As is well known to the majority of engineers in India, Mr. Shiv Narayan is a Professor at the Poona College of Engineering and for many years he has assiduously studied the science of hydro-electricity, his experience in this direction including several valuable years which he spent in the United States of America (and in the Kashmir State). He has also contributed many articles upon this subject to this Supplement and to other technical publications in India, and has thus earned a place in the select little coterie of publicists who have made the study of hydro-electrics peculiarly their own.

Mr. Shiv Narayan does not claim to advance any new theories in his book but rather to summarise the past history of hydro-electrics in India, to review the present position and to discuss something of its future in India as compared with other countries of the world; and that *he has succeeded in weaving dry-as-dust facts and figures into a thoroughly interesting and informative story is no small triumph in itself.* Actually, however, the Author has gone farther than that, for he has incorporated in his book a mass of information which for lack of a better term may be called "other peoples' views." The result is that the student, for whom the book is primarily intended, is provided with a valuable summary of leading engineers' views concerning the various hydro-electric installations in India but also with chapter and verse for *many weighty opinions* which had an important bearing upon modifications and changes in design in other works of a simillar nature.

In the first two chapters of his book, Mr. Shiv Narayan discusses the general principles of hydro-electric engineering and quotes a few essential formulæ which are illustrated by means of examples from installations in various parts of the country. With these preliminaries, upon which he does not devote any unnecessary space, the author comes to his subject proper and in the course of twelve chapters he describes the main features of every hydro-electric installation in the country, both in British India and in the Native States. There follow six chapters in the course of which the author discusses the economic problems of electric installations and gives a large number of statistical tables and other technical information and the book concludes with a chapter devoted to matters which became topical whilst the remainder of the book was in Press.

An abridged but uptodate edition of 'H. E. I. I.' called "*Hydro-electric Stations in India," has been issued at only one-half* the price of the former.

Superintending Engineer, India's Largest Hydro-Electric Scheme.

I have just finished your book on Hydro-Electrics in India and congratulate you on your successful enterprise. It is a **mine of information** and should spur the great Indian capitalists to beautify their great country with fine lakes and large industries......I have had much experience of Native States where money is plentiful and consider that your handbook should be carefully studied by the Ruling Chiefs and their Dewans...I hope you will soon be thinking of a second edition."

N.B.—A new book, abridging and supplementing the information given in the first book, has been issued under the name of *Hydro-electric Stations in India.*

Superintending Engineer, Electric Company, Bombay.

A most useful compilation......

Professor of Electrical Engineering, University of Nebraska, U. S. A.

Very interesting to know what the developments are and what the latent possibilities may be.

Professor of Electrical Engineering, Sibpur.

This great book on Hydro-Electric Engineering............very interesting.

Executive Engineer, Gwalior, Central India.

"......read your book......It is well-written and lucid......"

LATE MINISTER OF EDUCATION, BOMBAY.

Many thanks for your book. I cursorily went through it and found it very instructive.

Managing Director, Jost's Engineering Company.

Find it interesting.

S. K. Gurtu, M. I. C. E., **Engineer-in-Chief,** wrote in an issue of **"Indian Engineering":—**

"Professor Shiv Narayan has not only described in his book the different Hydro-Electric Installations of India, giving their salient points and special features, but has gradually built up principles of designing and drawing up specifications which will prove extremely useful to many engineers, who though not electricians have yet, in the exercise of their functions as Heads of Engineering Departments, to deal with hydro-electric schemes.

Professor Shiv Narayan's book will also help in drawing the attention of the authorities to the fact that if black coal is showing signs of exhaustion or cannot keep pace with the demand for it, white coal is lying scattered in profusion all over the continent of India and if properly exploited would give millions of horse-power...... in spite of so many possibilities of water-power development, few Governments have thought seriously of it......it may be hoped that Professor Shiv Narayan's book will interest them in water-power enter-prises and induce them to develop this new source of power.

Professor Shiv Narayan's book, while it provides pabulum for a trained electrician, is replete with notes and explanations which make the subject intelligible to everybody interested in the question of exploiting the new sources of power, whether as a Civil Engineer dealing with water-power schemes or as a financier desirous of examining for himself the merits of a scheme put forward before opening the purse strings; *e g.*, the 'Economic problems of electric installations', the illuminating notes on 'diversity and load factors,' voltage, etc.

The Professor not only draws attention to the numerous problems relating to the development of water-power but gives formulæ and calculations and shows their applications......a matter of utmost importance in the present state of general ignorance about this subject......

Engineering Editor, "Times of India," Bombay.

I must take an early opportunity of congratulating you upon the *very comprehensive* manner in which you have dealt with your subject...There *has long been a need for such a book*, both for students

in India and as a work of reference......I sincerely hope that it will soon run to a second edition......(This and the Review of March 17 reproduced above were both written after the Government publication, Triennial Report on Water-Power, had been reviewed by the "Times of India").

N. B.—The new book supplementing the first has been named *Indian Water Power Plants* and priced Rs. 5 only. *Hydro-electric Stations in India*, just issued, costs Rs. 3/12 only.

"**Indian And Eastern Engineer,**" Calcutta, while announcing the book before publication :—

Mr. Shiv Narayan's experience of his subject has been *highly practical*, both in the West and in the East and this combined with a distinctly literary bent ensures that his book will be of an *eminently readable* character while based upon practical knowledge: a combination which is not always found in 'Professors'. At the present time, a work on the "Hydro-Electric Installations of India should be *of wide utility......*"

The "**Indian Textile Journal,**" Bombay, April 1922.

The book is indispensable to engineers who desire to be up to date with the electrical undertakings and enterprises of this country. We commend the book to the notice of all who are interested in this subject.

Proceedings of American Society of Civil Engineers and Journal of American Institute of Electrical Engineers

This book presents in popular form the principal facts concerning the hydro-electric plants and projects of India. It also explains the hydraulic and electrical principles involved, the general design and installation of plants and the economic factors to be considered. The work is intended to direct attention to the water-power resources of the country and to serve as a guide to engineers and capitalists interested in utilisation of them.

"**Forman Christian College Monthly,**" Lahore, March 1923.

This is a students' book, intended mainly for students of technical schools and engineering colleges; the author has struck a happy medium between the theoretical and practical sides of the subject. The fundamental principles and outlines are well handled and the standard hydro-electric plants are logically developed. The book is directed towards the design and performance aspect of the subject rather than to the mathematical aspect, although it carries a sufficiency of relevant "Formulæ and examples" where necessary to make it a self-contained and useful book.

ELECTRICAL ENGINEERING BOOKLETS (Re. 1/-each).

Booklets { III—**Lightning, Lightning Conductors, Protectors and Arresters. I.—Electric Generators, Motors and Circuits.**

"**Indian And Eastern Engineer,**" November 1923.

This book of facts, figures and formulæ, written by Mr. Shiv Narayan, Professor of Electrical Engineering and Physics, Thomason College, Roorkee, is specially intended for the use of Indian students and engineers.

Professor Shiv Narayan is the author of several well-known text-books on electrical engineering, and **Electric Generators, Motors and Circuits** is the first of a new series of electrical engineering booklets which he intends publishing.

These booklets comprise, in the main, some of the author's casual contributions to various technical journals, one of the chief being **The Indian and Eastern Engineer,** and if they all prove as successful as the first of the series, *they should become standard works for the use of students in the various engineering colleges of India.*

Principal and Professor of Physics, Government College, Lahore.

I acknowledge with thanks receipt of your booklet on **Electric Generators, Motors and Circuits.** *It is well-illustrated, considering the price of the book and it should prove very useful to students preparing for examinations.*

"**Indian Engineering,**" Calcutta, October 6th. 1923.

This little volume containing important facts, figures and formulæ written with particular reference to Indian conditions, as far as the technical character of the subject permits, giving an intelligent explanation of the essential facts and figures in a compact and clear form and indicating the directions in which the information imparted would probably be of assistance in later study or in practical life. *It can be studied with advantage by Indian students, engineers and industrialists and those interested in electrical engineering science and progress*......series of booklets represents the author's private study and research undertaken for his own sake and that of other students. **Mr. Shiv Narayan's** *publication ought to meet with a wide demand.*

Principal, V. D. J. H. Technical Institute, Lahore.

Your booklet is a welcome addition to the Institute Library, as it is a help to those possessing a slight knowledge of the subject.

"Industry," December 1923.

Professor Shiv Narayan has built up a reputation for himself as the author of several practical treatises (on hydro-electric engineering). *All his works are marked by lucidity and conciseness and are amply illustrated.* The book under review deals with different kinds of generators and motors; the mechanism of dynamos; the laws of current in the circuits and allied items. The subject *is clearly expounded and elucidated with facts, figures and formulæ.*

Late Professor of Electrical Engineering, College of Engineering, Poona.

I have looked through the booklet. It *is useful to students* in as much as it collects together in a concise form the fundamental facts and figures which every student is expected to know......deals with the most important matter of the subject.

Professor of Electrical Technology, Indian Institute of Science, Bangalore.

I think, the book on Lightning Protection should prove valuable.

Indian Engineering, February 16th, 1924.

Lightning.—This is the third of a series of Electrical Engineering Booklets dealing with the erection and testing of Lightning Conductors. How to guard buildings and machines, telegraph and transmission lines and systems.

The author's aim has been to give an intelligent explanation of the essential facts and figures in a compact and clear form, with reference to Indian conditions so far as the technical character of the subject permits. *In this, Mr. Shiv Narayan has been very successful and technical students and engineers will find the booklet most useful. The work contains up-to-date information and illustrations.*

Journal of the American Institute of Electrical Engineers. Proceedings of the American Society of Civil Engineers, Mechanical Engineering and Mining and Metallurgy, February 1924.

Electric Generators, Motors and Circuits, (32pp, 19 illustrations, diagrams). **Lightning...Conductors, Protectors and Arresters.** (35pp., 17 illustrations, diagrams).

The pamphlets by the Professor of Electrical Engineering and Physics at Thomason College, Roorkee, India, and intended for students and those in search of elementary information on these

subjects. The first contains data on direct current generators, motors and circuits; the second describes lightning and the methods in use to protect buildings, machinery and electric lines. The books are not mathematical and the author endeavours to present his information in an interesting way.

Indian and Eastern Engineer, February 1924.

This series of booklets is being designed to meet the need for *suitable and inexpensive handbooks* for Indian students of the Engineering profession, and the third volume fulfills its purpose as adequately as its two predecessors. *The text is well written in simple language and the illustrations are both numerous and well-executed.*

A Water Works Engineer, Aligarh, September 1937.

I have gone through the books and I am confident that the books will be very useful to beginners and practical operators.

Book in Preparation :—Wireless Stations in India.

Books by

DR. (PROF.) SHIV NARAYAN, Sc.D., F.R.S.A., Mem. A.I.E.E., M.I.E. (Ind.)
Chartered Electrical Engineer,
Retired Principal, College of Engineering, Poona.

1. *Electric Railways in India,* Rs. 4–8.
2. *Electric Generators, Motors and Circuits,* Re. 1–0.
3. *Lightning Conductors, Protectors and Arresters,* Re. 1–0.
4. *Hydro-electric Stations in India,* Rs. 3–12.
5. *Indian Water Power Plants,* about 200 pages, 35 illustrations. Price Rs. 5 only, is like the other books mentioned above,

Obtainable from (1) Messrs. D. B. Taraporewala Sons & Co., Booksellers, Bombay and (2) Messrs. Brij Narayan, A. M. A. I. E. E. ~~& Co., Ganeshkhind Road, Poona 5/~~

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